Maintaining Balance in Elderly Fallers

Novel aspects of postural balance measures in elderly

Jaap Swanenburg

The research was supported by:

Department of Rheumatology and Institute for Physical Medicine, University Hospital Zurich
SanofiAventis Pharma Switzerland
Novartis Switzerland
Nycomed Switzerland
Albert Böni Foundation

Swanenburg, Jaap
Thesis University of Groningen, the Netherlands – with ref. –with summary in English and Dutch

Cover: Fabrizio Rutishauser

Printed by: Druckerei der Stiftung Zentralstelle der Studentenschaft
der Universität Zürich

ISBN: 978-90-367-3976-4 (book version)
ISBN: 978-90-367-3977-1 (digital version)

Copyright © 2009 by J.Swanenburg

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photography, recording or any information storage or retrieval system, without prior written permission of the copyright owner.

All published papers are reprinted with permission.

RIJKSUNIVERSITEIT GRONINGEN

Maintaining Balance in Elderly Fallers
Novel aspects of postural balance
measures in elderly

Proefschrift

ter verkrijging van het doctoraat in de
Medische Wetenschappen
aan de Rijksuniversiteit Groningen
op gezag van de
Rector Magnificus, dr. F. Zwarts,
in het openbaar te verdedigen op
maandag 12 oktober 2009
om 13.15 uur

door

Jaap Swanenburg
geboren op 25 februari 1969
te Dielsdorf, Zwitserland

Promotor:	Prof. dr. T. Mulder
Copromotores:	Dr. E.D. de Bruin Dr. D. Uebelhart
Beoordelingscommissie:	Prof. dr. J. Arendzen Prof. dr. E. Otten Prof. dr. E. J.A. Scherder

Paranimfen: Dr. T. Delley and R. Knols

Contents

Chapter 1

Postural balance measures in elderly fallers

In 2005, approximately 15% of the population in the more developed countries were 65 years of age or older. According to the United Nations Medium Variant population projection, this number will increase to over 26% by 2050[1]. Therefore, identification of potential fallers and, thus, possible prevention of falls is a very relevant aim[2]. Over one-third of the community-dwelling elderly older than 65 years of age suffer from a fall each year[2,3]. Falls cause up to 11% of serious injuries and up to 9% of fractures[4-6]. Therefore, identification of potential fallers and, thus, possible prevention of falls is a very relevant aim[7]. However, even minor injuries may trigger the vicious circle of fear and limited mobility, which in turn have adverse effects on overall health and increase the risk for additional falls and disability[8]. Minimizing the risk of falling would lead to a reduction in the risk of a fracture and therefore reduce suffering and costs.

Many different intervention programs have been developed to reduce the burden of falls and fractures. However, reliable tools are still needed for controlling the effectiveness of fall intervention programs and for the early identification of fallers. Currently, different methods are used to fulfill these objectives such as observational performance tests to assess the risk of falling and performance measurements using all types of equipment[9]. For observational performance tests, several assessment tools are available that combine measures of balance with measures of gait and mobility to determine a person's risk of falling, e.g., the Berg Balance Scale and the Tinetti Gait and Balance Assessment[10,11]. Furthermore, many devices exist for assessing performance, measuring for example, static balance, dynamic balance, walking velocity and mobility, muscle strength, and so on[9].

A device that is frequently used for the assessment of fall risk is the force platform. With a force platform, researchers and clinicians can quantify balance abilities[12]. These force platforms produce a wide range of force platform variables by which the postural stability can be described in objective terms. However, until now no force platform derived variables have been identified that are able to discriminate between elderly fallers and nonfallers [13]

Besides the ability to discriminate between elderly fallers and nonfallers, another aim of postural balance assessment is the prediction of falls in the future. Early identification of persons at risk could help to prevent possible injuries. If this would be possible intervention programs that aim to improve postural control could be tested for their effectiveness. Unfortunately, there are almost no studies that have a used a prospective design with falls as their primary outcome[14] The status of force platform assisted techniques for the prediction of future falls is, therefore, at present only limited.

Hence, it can be argued that there is a need for studies that identify variables from force platform assessment techniques that can be used for prediction of future fall risk and can be used as an outcome measure in intervention-type studies.

When assessment protocols with force platform techniques are designed, it is important that the behavioral context is considered, that is to say, performing a balance task always takes place in some environmental and task-related context. It never takes place *in vacuo*. This means that the measurement environment plays an important role. Many studies used the force platform technique for the performance of a static stance task (standing still) with or without vision. However, it can be argued that such an assessment does not really mimic "real-world" conditions and, therefore, may not be challenging enough for many elderly persons[15]. These single-task test conditions give participants the opportunity to compensate for possible deficits by shifting toward other control strategies[15]. By employing an additional task, next to the primary task (e.g. standing), a more "real live mimicking" environment will be created. The assumption, hence, is that by following a dual task test procedure the tested subjects will exhibit more difficulty with the shifting toward other control strategies and, thus, possible deficits will be more easily discovered.

There is some evidence that measurements using a dual-task protocol could have additional value compared to single-task testing for the prediction of falls[16]. At present, however, it is unclear what kind of additive task should be integrated in clinical protocols.

New insights into the results of quantitative posturography measures in elderly fallers and nonfallers are described in this thesis. This thesis explores variables from force platform assessment techniques that can be used for prediction of future fall risk and that can be used as outcome measures in intervention-type studies.

Outline of the thesis

The first objective of this thesis is to examine an intervention program that is assumed to influence postural control and post-intervention fall risk. Chapter 2 presents the results of a randomized clinical trial in elderly persons with decreased bone mineral density. The aim of this study was to investigate whether exercise combined with protein intake and calcium/vitamin D supplementation would have a larger (positive) effect on risk of falling and force platform derived postural balance outcomes compared with calcium/vitamin D supplementation only. Additional outcome measures that were used in this study are an observational balance performance test (Berg Balance Test).

The second objective of this thesis, delineated in Chapter 3, is to evaluate force platform measures of postural control. This chapter investigates whether a dual-task protocol is able to cause more disturbances of postural control in comparison to a single task only. Various types of secondary tasks are investigated to determine the most appropriate task for the elderly in a clinical setting. The task selection is based on theoretical considerations as well as on the practical feasibility. Furthermore, this chapter explores whether differences exist between fallers and nonfallers in terms of disturbance of postural control under the different additional tasks.

Chapter 4 describes the interrater and test–retest reliability of force platform variables from the dual-tasking test protocol that was described in Chapter 3.

In Chapter 5, a prospective study with 270 participants is described. The aim of this study was to determine whether force platform variables measured under dual-task testing conditions with a force platform were able to prospectively predict fallers and nonfallers in a community-dwelling elderly population over a 12-month period.

Finally, in Chapter 6, a study is described that investigates postural balance change caused by no-vision and/or compromised somatosensory information in single and dual tasking. This study also wanted to determine the (change in) dual-task costs caused by the reduction of combined sensory input.

References

1. United Nations. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. World Population Prospects: The 2006 Revision and World

2. Hausdorff JM, Rios DA, Edelber HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. Arch Phys Med Rehabil. 2001;82:1050–1056.

3. Hornbrook MC, Stevens VJ, Wingfield DJ, Hollis JF, Greenlick MR, Ory MG. Preventing falls among community-dwelling older persons: results from a randomized trial. Gerontologist. 1994;34:16–23.

4. Gostynski M, Ajdacic-Gross V, Gutzwiller F, Michel JP, Herrmann F. Epidemiological analysis of accidental falls by the elderly in Zurich and Geneva. Schweiz Med Wochenschr. 1999;129:270–275.

5. Oakley A, Dawson MF, Holland J, Arnold S, Cryer C, Doyle Y, Rice J, Hodgson CR, Sowden A, Sheldon T, Fullerton D, Glenny AM, Eastwood A. Preventing falls and subsequent injury in older people. Qual Health Care. 1996;5:243–249.

6. Rubenstein LZ, Josephson KR, Robbins AS. Falls in the nursing home. Ann Intern Med. 1994;121:442–451.

7. Murphy SL. Deaths: final data for 1998. Natl Vital Stat Rep. 2000;48:1–105.

8. Stevens JA, Sogolow ED. Gender differences for non-fatal unintentional fall related injuries among older adults. Inj Prev. 2005;11:115–119.

9. Rogers ME, Rogers NL, Takeshima N, Islam MM. Methods to assess and improve the physical parameters associated with fall risk in older adults. Prev Med. 2003;36:255–264.

10. Berg KO, Maki BE, Williams JI, Holliday PJ, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. Arch Phys Med Rehabil. 1992;73:1073–1080.

11. Tinetti ME, Williams TF, Mayewski R. Fall risk index for elderly patients based on number of chronic disabilities. Am J Med. 1986;80:429–434.

12. Horak FB. Clinical assessment of balance disorders. Gait Posture. 1997;6:76–84.

13. Palmieri RM, Ingersoll CD, Stone MB, Krause BA. Center-of-pressure parameters used in the assessment of postural control. Journal of Sport Rehabilitation. 2002;11:51–66.

14. Piirtola M, Era P. Force platform measurements as predictors of falls among older people—a review. Gerontology. 2006;52:1–16.

15. Mulder T, Zijlstra W, Geurts A. Assessment of motor recovery and decline. Gait Posture. 2002;16:198–210.

16. Zijlstra A, Ufkes T, Skelton DA, Lundin-Olsson L, Zijlstra W. Do dual tasks have an added value over single tasks for balance assessment in fall prevention programs? A mini-review. Gerontology. 2008;54:40–49.

Chapter 2

Effects of exercise and nutrition on postural balance and risk of falling in elderly people with decreased bone mineral density: randomized controlled trial pilot study.

Jaap Swanenburg
Eling D. de Bruin
Marguerite Stauffacher
Theo Mulder
Daniel Uebelhart

Clinical Rehabilitation 2007; 21: 523–534

Abstract

Objective: To compare the effect of calcium/vitamin D supplements with a combination of calcium/vitamin D supplements and exercise/protein on risk of falling and postural balance. ***Design:*** Randomized clinical trial. *Setting:* University hospital physiotherapy department. ***Subjects:*** Twenty-four independently living elderly females aged 65 years and older with osteopenia or osteoporosis, and mean total Hip T-score (SD) of -1.8 (0.8). ***Interventions:*** A three-month programme consisting of exercise/protein including training of muscular strength, co-ordination, balance and endurance. Calcium/ vitamin D was supplemented in all participants for a 12-month period. ***Outcome measures:*** Assessment took place prior to and following the months 3, 6, 9 and at the end of the study; primary dependent variables assessed were risk of falling (Berg Balance Test) and postural balance (forceplate). Secondary measures included body composition, strength, activity level, number of falls, bone mineral content, biochemical indices, nutritional status and general health. ***Results:*** Significant reductions of risk of falling (repeated measures ANOVA $F=8.90$, $p=0.008$), an increase in muscular strength (ANOVA $F=3.0$, $p=0.03$), and an increase in activity level (ANOVA $F=3.38$, $p=0.02$) were found in the experimental group as compared to the control group. Further on, there was 89% reduction of falls reported in the experimental group (experimental pre/post 8/1 falls; control group pre/post 5/6 falls). ***Conclusion:*** This study provides support for our intervention programme aimed at reducing the risk of falling in elderly participants diagnosed with osteopenia or osteoporosis. The data obtained from the pilot study allow the calculation of the actual sample size needed for a larger randomised trial.

Chapter 3

Compromising postural balance in the elderly

Jaap Swanenburg
Eling D. de Bruin
Daniel Uebelhart
Theo Mulder

Gerontology 2009, 55:353-360

Abstract

Background: Additional tasks that are assumed to disturb standing postural control can be divided in added motor or added cognitive tasks. It is unknown, which type of task causes the most disturbances on postural control in elderly. ***Objective:*** The aim of this study was to determine whether the dual tasking disturbance of postural control in elderly is caused by vocal articulation or by limited attentional resources. ***Methods:*** 39 elderly (81 ± 7 years) were tested on a force platform in a two-legged standing position. Seven balance variables were assessed: maximum displacement and standard deviation amplitude in the medial-lateral (Max-ML, RMS-ML) and anterior-posterior (Max-AP, RMS-AP) direction, average speed of displacement (V) and the area of the 95th percentile ellipse (AoE) and sway path (PL) per given time. The following task combinations were tested: *no secondary task*, *repeating a number aloud* (articulation), *counting backwards aloud* (articulation and attention), and *counting backwards silently* (attention). All tasks were tested with and without vision. ***Results:*** A factorial ANOVA revealed main effects of additional tasks in PL, Max-ML, RMS-ML, Max-AP, AoE and V. Bonferroni post-hoc analysis in a with vision situation showed significant difference between *no task* and *counting backwards aloud task* in balance variables Max-ML (p=0.006), RMS-ML (p=0.002), Max-AP (p=0.020) and V (p=0.003) respectively. All no-vision situations showed no significant difference between the different tasks. ***Conclusion:*** The findings suggest that the combined articulation and attention demanding secondary task stressed the attentional system of elderly to such extend that it compromised the performance of the primary task (quite standing). The *counting backwards aloud* task may be used as dual task for clinical balance assessment in at risk populations. This task was best able to disturb postural control.

Chapter 4

The reliability of postural balance measures in single and dual tasking in elderly fallers and non-fallers.

Jaap Swanenburg
Eling D. de Bruin
Kathrin Favero
Daniel Uebelhart
Theo Mulder

BMC Musculoskelet Disord. 2008 Dec 9;9(1):162.

Abstract

Background: The purpose of this study was to determine the reliability of a forceplate postural balance protocol in a group of elderly fallers and non-fallers. The measurements were tested in single and dual-task conditions, with and without vision. ***Methods:*** 37 elderly (mean age 73 ± 6 years) community-dwellers were included in this study. All were tested in a single (two-legged stance) and in a dual-task (two-legged stance while counting backwards aloud in steps of 7`s) condition, with and without vision. A forceplate was used for registering postural variables: the maximal and the root-mean-square amplitude in medio-lateral (Max-ML, RMS-ML) and antero-posterior (Max-AP, RMS-AP) direction, mean velocity (V), and the area of the 95% confidence ellipse (AoE). Reliability of the test protocol was expressed with intraclass correlation coefficients (ICC), with 95% limits of agreement (LoA), and with the smallest detectable difference (SDD). ***Results:*** The ICCs for inter-rater reliability and test-retest reliability of the balance variables were r= 0.70-0.89. For the variables Max-AP and RMS-AP the ICCs were r=0.52-0.74. The SDD values were for variable Max-ML and Max-AP between 0.37cm and 0.83cm, for V between 0.48cm/s and 1.2 cm/s and for AoE between 1.48cm^2 and 3.75cm^2. The LoA analysis by Bland-Altman plots showed no systematic differences between test-retest measurements. ***Conclusion:*** The study showed good reliability results for group assessment and no systematic errors of the measurement protocol in measuring postural balance in the elderly in a single-task and dual-task condition.

Background

Various balance tests[1,2] and measurements[3-7] have been developed and presented to obtain appropriate information of balance capabilities during standing. Although tests for postural control with functional balance scales are easy to perform and are suitable for daily clinical use they often lack accuracy. Technology based laboratory systems may give more detailed information about postural balance[8], but are often difficult to use in a clinical setting.

Quantitative posturography is a frequently used technique for measuring postural control[9]. This technique covers all force platforms used to quantify postural control in upright stance in either static or dynamic conditions. The employed force platform indirectly detects changes of postural sway by assessing the ground-reaction forces. These ground-reaction forces are used to calculate the centre of pressure (COP), which reflects the trajectory of the centre of mass and the torque acting on the surface[10]. Various balance variables can be derived from the COP movement, e.g. the root mean square (RMS) of COP amplitudes in anterior-posterior and medio-lateral direction or the maximum COP displacement in anterior-posterior and medio-lateral direction[11-15]. It is assumed that these measures relate to impaired postural control in humans. However, in spite of the frequent use of these measures only a small number of studies have reported on the reliability of postural balance measures[12-17].

Commonly identified flaws in reliability studies are the exclusive use of healthy individuals, questionable applicability in clinical practice, low sample size, the absence of a protocol and the use of inadequate statistics [18]. It is questionable whether the test results of healthy elderly for example can be generalized to specific sub-populations, e.g. fallers, in clinical practice. Only very few studies tested the reliability of postural assessment with a force platform in patient groups. Benvenuti and colleagues (1999) assessed patients with a variety of chronic pathologic conditions resulting in balance problems; however, they did not specifically focus on fallers or non-fallers [16]. Stroke survivors and patients suffering from diabetic neuropathy were assessed by Corriveau and colleagues (2001) but these authors excluded subjects if they reported visual or somatosensory impairments or reported at least 1 fall in the past year[17]. The same exclusion of fallers was performed by Lafond et al. (2004)[15].

There seems to be a need to perform reliability assessments of postural control in groups with identified fallers and non-fallers. No reliability studies have been reported that specifically included fallers. However, since one-third of community-dwelling people over 65 years of age experience one or more falls each year, it seems important to include elderly fallers in reliability studies[18- 22].

The applicability of test measures in clinical practice is another important point to consider. Most reliability studies used single-task procedures consisting of standing quietly while manipulating the visual input and/or changing the base of support (BOS). Mulder et al. (2002) argued that although a motor system may deteriorate across time, many assessment procedures show no changes in performance. The authors state that this phenomenon is related to the fact that the level of functional reorganization of a (changing) motor system is not necessarily reflected in the 'pure' end-result of a task, but might be reflected also in the increasing compensatory costs across time[23]. This would mean that assessment procedures that are used in clinical practice should also be sensitive to this phenomenon when we want to be able to detect possible underlying pathologies. In other words the compensatory costs, necessary to keep the motor output optimal, should be estimated in clinical protocols.

The basic idea behind the dual-task methodology is that the performance of a difficult (nonautomated) task interferes with other simultaneously performed tasks[24]. Hence, by employing an attention demanding task, it is possible to use the degree of interference of this task with the primary task (e.g. standing) as a measure of the attention demands (cognitive compensation) of the primary task. There is indeed a growing use observable of dual-task procedures in studies focusing on recovery after damage to the motor system[25] or in neurological assessment[26]. However, there are not many studies that include reports on the reliability of the used protocols. We found only one study that focused on the reliability of the postural measures and that used a simultaneous secondary task during performance of the primary (postural) task[4]. At the same time it has been reported that falls seem to occur frequently during activities in which attention has to be divided between two tasks[27]. This observation further underscores the potential value and necessity of dual task testing. Furthermore, because of inconsistencies in the design and analysis of method evaluation studies, a high proportion of prognostic studies were presented with poor methodology which resulted in the presentation of conflicting interpretation of variability of the measures. This led the Work Package 3 of the Prevention of Falls Network Europe to formulate criteria for evaluation of measurement properties of clinical balance measures for fall prevention studies[28].

The purpose of the present study was, therefore, to determine the interrater and test-retest reliability of quantitative postural control measures in elderly fallers and non-fallers, tested under single and dual-task conditions, with and without vision, and considering both relative and absolute reliability.

Methods

Participants

Thirty-seven community dwellers participated in the study (29 women), the average age was 73 ± 6 years (range 61–85 years). The inclusion criteria were fallers and non-fallers older than 60 years of age of both genders. Exclusion criteria were participants who were unable to understand (language) the purpose of the study, severe psychological or psychiatric problems, chronic substance-abuse (medication, drugs and/or alcohol), and patients under chronic therapy with neuroleptics, sedatives, anti-epileptics and anti-depressives. A structured interview that considered recommendations on falls outcome measures [29] was used to assess the numbers of falls in the previous year. A fall was defined as any event that caused unintentional contact by the torso or upper limbs to the ground or to some lower level, other than as a consequence of a violent blow, loss of consciousness, or a sudden onset of paralysis as in stroke or epileptic seizure[30]. A faller was defined in this study as a subject that sustained more than one fall within the last 12 months. The measurements took place at the Institute of Physical Medicine (Department of Rheumatology), University Hospital Zurich. All participants gave their informed written consent and were blinded to the purpose of the measurements. The study was approved by the local ethics committee.

Experimental procedure

The AMTI Accusway system for balance and postural sway measurement (Advanced Mechanical Technology, Inc., Watertown, Massachusetts) was used for collecting the data. The Accusway system consists of a portable force platform and SWAYWIN software for data acquisition and analysis. The system measures ground reacting force and moments in 3 orthogonal directions with a sampling frequency of 50Hz. These provide the COP coordinates, which enables the calculation of the maximum displacement in the anterior-posterior and medial-lateral direction (Max-AP ; Max-ML), the root-mean-square amplitude in anterior-posterior and medial-lateral direction from the centroid in x- and y-axis (RMS-AP ; RMS-ML), the mean velocity (V) and the area of the 95th percentile ellipse (AoE).

Before the measurements took place, the balance platform was strapped with an anti-slip plastic cover (1mm). The participant then took a comfortable barefooted, double-legged stance on the platform. Because changes in the Base of Support (BOS) have a substantial effect on postural control[14]; the outlines of both feet were marked on the plastic cover with a permanent marker in order to obtain standardised individual foot positions for the repeated measurements. After leaving the platform, the individual's BOS was entered in the Accusway Plus system[31]. Maximal BOS width and hip width, measured at the major trochanter femoris, were recorded with an anthropometric calliper (Lafayette Instrument Company, Lafayette, IN).

Measurement design

The participants were tested individually within a single session that lasted about 25 minutes. First, instructions of the cognitive task were given, followed by a full performance of the cognitive tasks while seated. Thereafter, the participants were instructed to stand on the pre-marked plastic cover with the arms by the sides and eyes open while looking straight ahead.

The postural balance measurements were collected under two task conditions: standing quiet (without a secondary cognitive task) and standing quiet combined with counting backwards in steps of seven. Each task consisted of 4 trials and the average of the 4 trials was taken to obtain a reliable measure[17]. Each separate trial lasted 20 seconds, followed by a break of 20 seconds[32]. The total 20 seconds of the trial was used for the calculations. Between each task, the participants were allowed to sit down for a 2-minute break. Both tasks were measured with and without vision. The order of tasks (single, dual, with and without vision) was changed randomly to control for the effects of fatigue and learning. The rationale for this procedure was primarily based on the fact that the duration of a trial in quiet standing is limited due to fatigue, particularly in pathologic elderly [15]. Furthermore, the optimum test-retest reliability for our protocol was assumed to be obtained at 20s trial durations[32], and we wanted a test that is feasible to be implemented in a clinical setting where time constraints play an important role.

Cognitive task

Counting backwards, as a cognitive task, showed significant degradation in postural stability in healthy adults and healthy elderly[33-35]. Therefore counting backwards in steps of 7`s was also used as additional task in the present study. The participant was asked to count back as fast and accurate as possible in 20 seconds[36,37]. If the counting backwards in steps of sevens was too difficult, steps of threes or ones were used instead. The starting number was selected at random from a range of 80-99. For those participants who were able to count back to zero within 20 seconds a starting number was selected within the range of 121 and 199. The counting was controlled continuously for accuracy and every mistake was noted. No feedback on performance was given during the testing. Evaluation of performance during the cognitive task included the difficulty (sevens, threes or ones) of subtraction units and the number of mistakes made by the participant during calculation.

To evaluate the performance of the cognitive task the difficulty (sevens, threes or ones) of subtraction and the number of mistakes made by the participant during the calculation were used to define 6 performance scores (Cognitive Difficulty Score, CDS). The lowest score is designated number 1 and is given when mistakes are made during counting backwards in ones. The highest score (6) is given when counting backward in sevens is possible without making mistakes. With increasing numerical complexity the CDS is increasing. An overall group score (GS) was calculated by taking a mean of all individual scores (Table 1).

Table 1
Cognitive Difficulty Score, taking in accounting difficulty and mistakes made during dual tasking.

Difficulty Counting Backwards	Mistakes Made	Cognitive Difficulty Score
1	Yes	1
1	No	2
3	Yes	3
3	No	4
7	Yes	5
7	No	6

Visual conditions

The two tasks were tested under two different visual conditions:

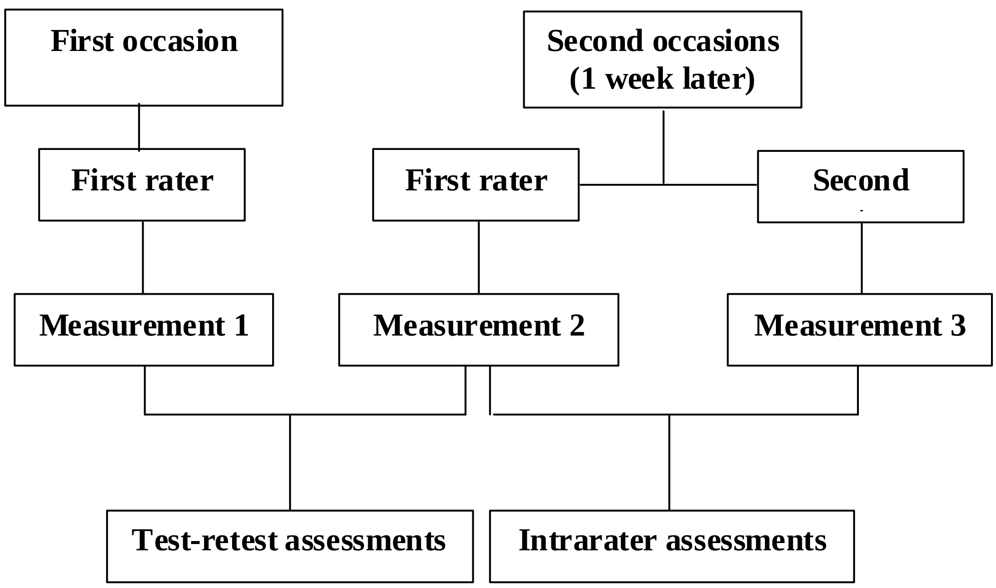
a) Normal vision; the participants were instructed to view a fixed grey cross; the arms of the cross were 1 meter long and aligned horizontal. The vertical arms were 0.5 meter long. The cross was located in the middle of a screen (1.5m x 1.5m), which was positioned 2 meters in front of the forceplate. The height of the grey cross was fixed at 1.5m. All participants used their own glasses when needed, to have optimal individual visual acuity.

b) Vision was occluded with a pair of custom-made opaque goggles that prevented the subject from perceiving visual information without blocking the light in general. The participants were instructed to keep their eyes open inside the goggles.

Reproducibility protocol

For the test-retest study, all participants were evaluated by the first rater on 2 occasions with an inter-measurement interval of 7 days. Both measurements were performed at the same time of the day in the same measurement room. Additionally at the second measurement occasion the second rater performed a third measurement to evaluate the interrater reliability. The order of the rater was changed after each participant (Figure 1).

Figure 1
Flow diagram of assessments timeline



Statistical analysis

Descriptive statistics were used to describe the participant's characteristics. The one-sample Kolmogorov-Smirnov test was used to check the normality of the distributions.

De Vet and colleagues (2006) recently suggested using both reliability and agreement parameters in reliability studies because this allows gaining a better insight on the performance of measuring a variable[38]. Reliability parameters assess whether a measurement device can distinguish between groups of patients and between individual patients [3]. Agreement parameters measure the ability to achieve the same value in two measurements, and thus give an indication of the size of the measurement errors[40].

Reliability parameters

The intraclass correlation coefficient (ICC) was used as a parameter of reliability. The ICC(2,1) model was selected to test the interrater reliability, and the ICC(3,1) model to estimate the test retest reliability[41,42.]

Agreement parameters

For both the test-retest and the interrater reliability the smallest detectable differences (SDD) were determined by the 95% SEM (1.96 √ 2 √ SEM; SEM = √mean square error)[43,44].

The 95% limits of agreement (LoA) were for both the test-retest and the interrater reliability assessed according Bland and Altman. LoA was calculated by: mean of the differences ± 1.96*SD.

LoA indicates the total error, which is systematic error and random error combined. Discrepancies between measurements were also assessed by visual interpretations of the amount of agreement of the means of two trials against the difference between the trials (Bland and Altman Plots). The use of 95% confidence intervals of the range of differences between the two trials demonstrates how close the measurements agree on different occasions. All calculations were considered as significant at the 5% confidence level[45].

The data were entered, stored, and analysed in SPSS 12.0.1 statistical software (SPSS, Inc., Chicago, IL)

Results

A total of 37 participants were recruited (29 women), the average age was 73 ± 6 years (range 61–85 years) and a total of 11 fallers were identified. The participant's characteristics are shown in Table 2.

Table 2
Participants' characteristics

	All (n=37)	Non-fallers (n=26)	Fallers (n=11)	*P*
Female	29	18	11	
Male	8	8	0	
Age; y (SD)	73 (6)	71 (6)	76 (4)	ns.
Range	61/85	61/85	67/83	
Weight; kg (SD)	67 (11)	69 (11)	64 (12)	ns.
Height; cm (SD)	165 (7)	166 (8)	161 (5)	**0.05**
Hip width (cm)	34.2(3)	34.4(2)	33.7(4)	ns.
BOS width (cm)	27.7(4)	29.4(3)	30.5(4)	ns.

SD= Standard Deviation; *P*= unpaired t-tests; *p<0.05 fallers and non-fallers; ns= not significant, BOS = base of support

All participants were able to count backward in steps of sevens. A total of 20 participants made counting mistakes, whereas 17 made no mistakes. The group score (GS) of first rater measurements in both occasions was 5.5. The second rater reported a GS of 5.4 within his measurement (maximal GS possible is 6; see Table 3). There was no significant difference in GS between the raters.

Reliability parameters

Two force platform variables, which had no normal distribution, were log transformed and marked (see in Table 4 and Table 5). Our study showed good ICC values of the postural balance measurement protocol, e.g. test retest, as well as for interrater reliability. The ICC(2.1) for interrater reproducibility and the ICC(3.1) for test-retest reproducibility of the balance variables Max-ML, RMS-ML, V and AoE were ranging between r= 0.70-0.89. For the variables 'Max-AP' and 'RMS-

AP' the ICCs ranged between r=0.52-0.74. The results of the interrater ICCs are summarised in Table 4 and the results of the test-retest are presented in Table 5.

Table 3
Results of the Group Scores of Cognitive Difficulty Score, taking in accounting difficulty and mistakes made during dual tasking.

	All (n=37)	**Non-fallers (n=26)**	**Fallers (n=11)**	***P***
Group Score (GS)				
Rater 1 first occasion	5.5	5.5	5.4	ns.
Rater 1 second occasion	5.5	5.5	5.3	ns.
Rater 2 second occasion	5.4	5.4	5.4	ns.

p= unpaired t-tests; **p*<0.05 fallers and non-fallers; ns= not significant,

Agreement parameters

The SDD values for variables Max-ML and Max-AP were 0.37cm and 0.83cm respectively. Variable V lay between 0.48 cm/s and 1.2 cm/s. For variable AoE the SDD values were between 1.48 cm2 and 3.75 cm2 (see Table 4). To detect change in clinical practice beyond measurement error potential changes should be larger than these SDD values.

The LoA showed very small systematic error between test-retest and interrater agreement. The mean of the differences for variable Max-ML and Max-AP were between 0.0cm and 0.08cm. For variable V between 0.03cm/s and 0.18cm/s and for variable AoE between 0.06cm2 and 0.512 (see Table 6).

Table 4
Interrater Reliability Parameters

Balance-Variable	Vision	Task	All n=37 Interrater ICC 95% CI	Non-Faller n=26 Interrater ICC 95% CI	Faller n=11 Interrater ICC 95% CI
Max-ML (cm)	Vision	Single	0.76 0.60/0.87	0.80 0.60/0.90	0.72 0.28/0.91
		Dual	0.75 0.56/0.86	0.84 0.68/0.93	0.30 -0.38/0.75
	No-Vision	Single	0.73 0.53/0.85	0.78 0.57/0.90	0.55 0.01/0.85
		Dual	0.72 0.52/0.84	0.72 0.47/0.82	0.70 0.32/0.93
RMS-ML (cm)	Vision	Single	0.84 0.71/0.92	0.83 0.75/0.92	0.89 0.68/0.97
		Dual	0.71 0.51/0.84	0.75 0.51/0.88	0.45 -0.22/0.82
	No-Vision	Single	0.70 0.48/0.83	0.72 0.47/0.87	0.62 0.12/0.88
		Dual	0.86 075/0.93	0.87 073/0.94	0.83 0.47/0.895
Max-AP (cm)	Vision	Single	0.52 0.24/0.72	0.56 0.24/0.72	0.47 -0.07/0.81
		Dual	0.64 0.40/0.80	0.61 0.38/0.80	0.68 0.31/0.94
	No-Vision	Single	0.74 0.55/0.86	0.84 0.67/0.92	0.40 -0.21/0.92
		Dual	0.70 0.48/0.83	0.72 0.46/0.86	0.64 0.12/0.89
RMS-AP (cm)	Vision	Single	0.57 0.30/0.75	0.42 0.05/0.69	0.77 0.37/0.93
		Dual	0.46 0.16/0.68	0.40 0.13/0.68	0.77 0.29/0.93
	No-Vision	Single	0.73 0.54/0.85	0.85 0.69/0.93	0.45 -0.08/0.80
		Dual	0.72 0.51/0.84	0.75 0.51/0.88	0.60 0.04/0.88
V (cm/s)	Vision	Single	0.76 0.57/0.87	0.81 0.57/0.87	0.70 0.20/0.91
		Dual	0.85 0.72/0.92	0.80 0.60/0.90	0.95 0.82/0.98
	No-Vision	Single*	0.87 0.77/0.93	0.89 0.77/0.95	0.78 0.33/0.93
		Dual	0.84 0.72/0.92	0.85 0.70/0.93	0.83 0.51/0.95
AoE (cm^2)	Vision	Single	0.65 0.42/0.81	0.65 0.35/0.83	0.69 0.22/0.90
		Dual*	0.74 0.54/0.85	0.75 0.51/0.88	0.57 -0.02/0.86
	No-Vision	Single	0.66 0.43/0.81	0.76 0.54/0.89	0.67 -0.04/0.79
		Dual	0.81 0.66/0.90	0.83 0.65/0.92	0.69 0.17/0.91

*=log transformed

Table 5
Test-Retest Reliability Parameters

Balance-Variable	Vision	Task	All n=37 Test-Retest ICC 95% CI	Non-Faller n=26 Test-Retest ICC 95% CI	Faller n=11 Test-Retest ICC 95% CI
Max-ML (cm)	Vision	Single	0.77 0.60/0.88	0.75 0.52/0.88	0.71 0.46/0.95
		Dual	0.71 0.51/0.84	0.80 0.51/0.91	0.32 -0.31/0.76
	No-Vision	Single	0.75 0.56/0.86	0.83 0.65/0.92	0.53 -0.07/0.85
		Dual	0.77 0.59/0.87	0.81 0.62/0.91	0.59 0.03/0.87
RMS-ML (cm)	Vision	Single	0.79 0.63/0.89	0.73 0.48/0.87	0.71 0.55/0.86
		Dual	0.75 0.57/0.86	0.80 0.60/0.90	0.58 0.01/0.85
	No-Vision	Single	0.72 0.51/0.84	0.71 0.45/0.86	0.69 0.33/0.93
		Dual	0.85 0.73/0.92	0.88 0.75/0.94	0.86 0.15/0.90
Max-AP (cm)	Vision	Single	0.55 0.28/0.74	0.43 0.06/0.70	0.55 -0.04/0.85
		Dual	0.63 0.39/80	0.56 0.22/0.77	0.57 0.22/0.77
	No-Vision	Single	0.64 0.41/0.80	0.83 0.65/0.92	0.43 -0.19/0.81
		Dual	0.61 0.35/0.78	0.68 0.40/0.84	0.40 -0.22/0.79
RMS-AP (cm)	Vision	Single	0.51 0.23/0.71	0.31 -0.08/0.62	0.77 0.36/0.89
		Dual	0.54 0.27/0.74	0.55 0.21/0.77	0.50 -0.11/0.83
	No-Vision	Single	0.69 0.47/0.83	0.86 0.72/0.94	0.39 -0.24/0.80
		Dual	0.58 0.31/0.76	0.64 0.35/0.82	0.38 -0.25/0.79
V (cm/s)	Vision	Single	0.89 0.79/0.94	0.84 0.68/0.93	0.81 0.56/0.97
		Dual	0.84 0.71/0.91	0.82 0.64/0.92	0.82 0.34/0.88
	No-Vision	Single*	0.89 0.80/0.94	0.87 0.74/0.94	0.81 0.71/0.98
		Dual	0.79 0.63/0.89	0.78 0.55/0.89	0.75 0.54/0.96
AoE (cm^2)	Vision	Single	0.75 0.57/0.86	0.62 0.32/0.81	0.81 0.63/0.98
		Dual*	0.79 0.63/0.89	0.81 0.62/0.91	0.49 -0.11/0.83
	No-Vision	Single	0.70 0.50/0.84	0.73 0.49/0.87	0.60 0.04/0.87
		Dual	0.76 0.57/0.87	0.80 0.61/0.91	0.64 -0.15/0.82

*=log transformed

Table 6
Agreement parameters

	Vision	Task	Rater 1/1st Mean (SD)	Rater 1/2nd Mean (SD)	Rater 2 Mean (SD)	Test -retest LoA	Test-retest SDD	Interrater LoA	Inter-rater SDD
Max-ML (cm)	Vision	Single	0.61 (0.28)	0.61 (0.28)	0.57 (0.24)	0.00±0.37	0.37	0.04±0.34	0.34
		Dual	0.95 (0.65)	0.89 (0.48)	0.89 (0.54)	0.06±0.85	0.85	0.00±0.72	0.72
	No-Vision	Single	0.69 (0.30)	0.64 (0.23)	0.66 (0.26)	0.05±0.38	0.37	-0.03±0.35	0.35
		Dual	0.92 (0.43)	0.86 (0.41)	0.80 (0.37)	0.06±0.56	0.56	0.06±0.57	0.57
RMS-ML (cm)	Vision	Single	0.24 (0.09)	0.25 (0.10)	0.23 (0.09)	-0.01±0.13	0.12	0.02±0.10	0.09
		Dual	0.39 (0.25)	0.35 (0.16)	0.37 (0.26)	0.03±0.29	0.29	-0.02±0.31	0.32
	No-Vision	Single	0.29 (0.15)	0.26 (0.10)	0.26 (0.10)	0.03±0.18	0.18	0.00±0.15	0.15
		Dual	0.36 (0.17)	0.34 (0.17)	0.34 (0.21)	0.02±0.18	0.18	0.00±0.20	0.20
Max-AP (cm)	Vision	Single	0.85 (0.25)	0.84 (0.33)	0.83 (0.21)	0.01±0.55	0.55	0.01±0.53	0.53
		Dual	1.20 (0.52)	1.15 (0.44)	1.12 (0.39)	0.05±0.81	0.81	0.03±0.70	0.70
	No-Vision	Single	1.11 (0.48)	1.04 (0.35)	1.07 (0.32)	0.07±0.70	0.70	-0.03±0.48	0.48
		Dual	1.35 (0.59)	1.27 (0.39)	1.18 (0.35)	0.08±0.87	0.83	0.10±0.55	0.55
RMS-AP (cm)	Vision	Single	0.36 (0.09)	0.34 (0.12)	0.34 (0.09)	0.01±0.21	0.21	0.00±0.19	0.20
		Dual	0.46 (0.18)	0.45 (0.15)	0.45 (0.16)	0.00±0.31	0.30	0.00±0.32	0.32
	No-Vision	Single	0.44 (0.15)	0.41 (0.12)	0.43 (0.11)	0.03±0.20	0.20	-0.02±0.16	0.15
		Dual	0.50 (0.20)	0.48 (0.13)	0.45 (0.13)	0.02±0.30	0.29	0.03±0.18	0.18
V (cm/s)	Vision	Single	1.34 (0.57)	1.31 (0.47)	1.24 (0.35)	0.03±0.48	0.48	0.08±0.55	0.55
		Dual	1.83 (0.74)	1.75 (0.60)	1.76 (0.64)	0.08±0.75	0.75	-0.01±0.69	0.68
	No-Vision	Single	1.82 (0.91)	1.64 (0.64)	1.73 (0.86)	0.18±*0.90	0.98*	-0.09±*0.89	0.93*
		Dual	2.22 (1.33)	2.09 (0.74)	2.10 (0.90)	0.14±1.21	1.21	-0.01±0.92	0.92
AoE (cm^2)	Vision	Single	1.64 (0.99)	1.58 (1.13)	1.46 (0.81)	0.06±1.48	1.48	0.12±1.61	1.61
		Dual	3.78 (4.43)	3.27 (2.54)	3.34 (3.50)	0.51±*5.59	2.62*	-0.07±*4.25	2.92*
	No-Vision	Single	2.45 (1.87)	2.09 (1.26)	2.21 (1.33)	0.36±2.40	2.40	-0.12±2.10	2.11
		Dual	3.66 (3.17)	3.18 (2.22)	3.00 (2.53)	0.48±3.75	3.75	0.19±2.89	2.89

*=log transformed

Bland-Altman plots indicated that most points lie within the 95% limits of agreement for test-retest measurements. Only 2 to 3 outliers were found within the plots. In all tables the outliers show both positive and negative differences of the mean, which indicates no systematic effect. Balance variables had the smallest 95% limits of agreement when testing in a single task situation with vision. The opposite was found in the dual-task situation with and without vision. The Bland-Altman plots are presented in the additional file [see Appendix 1].

Discussion

The purpose of this study was to evaluate the reliability of a forceplate postural balance assessment protocol under single and dual-task conditions in elderly fallers and non-fallers.

This study showed good reliability parameters for the total group of participants although in the non-fallers subgroup the values were higher compared to the fallers (see Table 4). Hence, our findings show the relevance of including symptomatic populations in a reliability study as previously was suggested by Hoving and colleagues (2005)[18]. Furthermore, the results of our study are in line with previous studies that included symptomatic populations, e.g. patients suffering from diabetes, neuropathy or stroke survivors[17]. From a clinical perspective our procedure makes sense because we included symptomatic individuals in our sample. This indicates that the results can be generalised to similar populations in clinical settings. It can be expected that a normal population will, similar to our sample, consist of both fallers and non-fallers. This would mean that our results are generalisable to comparable clinical populations.

The ICC values were different for each balance variable that was assessed. Between the test conditions, vision or no-vision and single or dual task, there were differences in ICC values as well (Tables 4 & 5). The results were consistently better in the medial lateral direction compared to the moderate ICC values in the anterior posterior direction. From a clinical perspective these results are encouraging. Day and colleagues (1993) have demonstrated that deterioration of balance control in the elderly primarily occurs in the ML direction during quiet stance[46]. When responding to a plate perturbation older adults also frequently step to especially preserve lateral stability[47]. These findings might be an indication that the main focus in assessment should be put on the mediolateral force platform variables. In these cases there are no large differences in reliabilities of the test protocol between vision and no-vision and between single and dual-task testing conditions. Our protocol reveals no large differences in reliability between these test conditions. The most optimal variables that should be assessed when groups of subjects are compared seem to be Max-ML, RMS-ML, and V since these all show highest ICC values. On an individual subject assessment level the agreement parameters of the Max-ML, RMS-ML, and V variables seem to be promising too. However, future intervention type studies for individuals should substantiate this assumption.

These results are not in accordance with the results of Corriveau and colleagues (2001), who found better ICC values in the anterior posterior direction than in the medial lateral direction[17]. A possible explanation for these differences could be found in the different assessment protocols used. Our participants were expected to take a comfortable stance position and were expected to repeatedly use this individualised position. This meant that foot position was standardized for each subject, but not across subjects. This was in contrast to Corriveau and colleagues who asked their participants to take a pre-determined stance position of pelvis width.

It is well documented that with increasing stance width a disproportionate reduction in the angular motion about the ankles and feet; e.g. the ankle joint mobility in the frontal plane is reduced with feet apart[48]; can be observed that causes a large reduction in lateral body motion[46]. It is for this reason that we standardised foot positions as previously recommended[49].

The limits of agreement showed no systematic error (bias) between the two measurements of rater 1 (test-retest) or between the measurements of rater 1 and rater 2 (interrater). Our protocol, therefore, seems to be well suited for clinical applications where several clinicians are often responsible for the same kinds of measurement. The resulting SDD values were rather large. At this moment it is difficult to say whether the obtained SDD values are too large to detect clinically meaningful differences on an individual level and would, therefore, be clinically not relevant. SDD values provide information about the size of the error related to a measured value and in the amount of measurement error that should be taken into account when comparing two consecutive measurements. Therefore these SDD values imply to have a rather less satisfactory reliability for assessing individual changes in comparison to group changes. This assumption should be substantiated in further research. It might very well be that the changes caused by interventions are larger, especially in clinical populations, than the SDD found in our study.

With our protocol that has shown to have good reliability in both fallers and non-fallers the next step in research would be to test the validity of this protocol. For that purpose we should perform a prospective study in a group of older individuals that is threatened to fall. It can be argued that in such a measurement design our protocol may have predictive value for subsequent falls.

Conclusion

In conclusion, our measurement protocol showed good reliability for group assessment with no systematic errors in measuring postural balance in single-task and in dual-task conditions in a group of elderly fallers and non-fallers. These results may form a basis for further research examining, for example, the effects of physical exercise in elderly suffering from balance impairments. The value of the test protocol for individualised assessment remains unclear and should be subject to further research.

References

1. Mathias S, Nayak US, Isaacs B. Balance in elderly patients: The ”Get-up and Go” test. Arch Phys Med Rehabil 1986, 67: 387-389.

2. Berg KO, Wood-Dauphinee S, Williams JI, Gayton D. Measuring balance in the elderly: preliminary development of an instrument. Physiotherapy Canada 1989, 41: 304- 311.

3. Juntunen J, Ylikoski J, Ojala M, Matikainen E, Ylikoski M & Vaheri E. Postural body sway and exposure to high-energy impulse noise. Lancet 1987, 11: 261-264.

4. Briggs R, Gossman M, Birch R, Drews J, Shaddeau S. Balance performance among noninstitutionalized elderly women. Phys Ther 1989.

5. Wing AM, Clapp S, Burgess-Limerick R. Standing stability in the frontal plane determined by lateral forces applied to the hip. Gait Posture 1995, 3: 38-42.

6. Era P, Schroll M, Ytting H, Gause-Nilsson I, Heikkinen E, Steen B. Postural balance and its sensory – motor correlates in 75-year-old men and women: A cross-national comparative study. J Gerontol: Medical Sciences 1996, 51A: M53-M63.

7. Chang H, Krebs DE. Dynamic balance control in elders: Gait initiation assessment as a screening tool. Arch Phys Med Rehabil 1999, 80: 490-494.

8. Alexander NB. Using technology-based techniques to assess postural control and gait in older adults. Clin Geriatr Med 1996, 12: 725-44.

9. Horak FB. Clinical assessment of balance disorders. Gait Posture 1997, 6 (1):76-84

10. Goldie PA, Bach TM, Evans OM. Force platform measures for evaluating postural control: reliability and validity. Arch Phys Med Rehabil. 1989, 70:510-517.

11. Stelmach GE, Zelaznik HN, Lowe D. The influence of aging and attentional demands on recovery from postural instability. Aging (Milano). 1990, 2(2):155-61.

12. Geurts AC, Nienhaus B, Mulder TW, Intrasubject variability of selected force-platform parameters in the quantification of postural control. Arch Phys Med Rehabil ,1993, 74:1140–1150.

13. Corriveau H, Hebert R, Prince F, Raiche M. Intrasession reliability of the "center of pressure minus center of mass" variable of postural control in the healthy elderly. Arch Phys Med Rehabil. 2000, 81(1):45-8.

14. Melzer I, Benjuya N, Kaplanski J. Age-Related Changes of Postural Control: Effect of Cognitive Tasks. Gerontology. 2001, 47(4):189-94.

15. Lafond D, Corriveau H, Hebert R, Prince F. Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. Arch Phys Med Rehabil. 2004, 85(6):896-901.

16. Benvenuti F, Mecacci R, Gineprari I, Bandinelli S, Benvenuti E, Ferrucci L, Baroni A, Rabuffetti M, Hallett M, Dambrosia JM, Stanhope SJ. Kinematic characteristics of standing disequilibrium: reliability and validity of a posturographic protocol. Arch Phys Med Rehabil. 1999, 80(3): 278-87.

17. Corriveau H, Hebert R, Prince F, Raiche M. Postural control in the elderly: an analysis of test-retest and interrater reliability of the COP-COM variable. Arch Phys Med Rehabil. 2001, 82(1) 80-5.

18. Hoving JL, Pool JJ, van Mameren H, Devillé WJ, Assendelft WJ, de Vet HC, deWinter AF, Koes BW, Bouter LM. Reproducibility of cervical range of motion in patients with neck pain. BMC Musculoskelet Disord. 2005, 136:59.

18. Hausdorff JM, Edelberg HK, Mitchell SL, Goldberger AL, Wei JY. Increased gait unsteadiness in community-dwelling elderly fallers. Arch. Phys. Med. Rehabil. 1997, 78:278–283.

19. Shumway-Cook A, Baldwin M, Polissar NL, Gruber W. Predicting the probability for falls in community-dwelling older adults. Phys Ther. 1997, 77(8):812-9.

20. Spirduso, W.W. Balance, posture and locomotion: Physical Dimensions of Aging Spirduso WW (Ed.). Illinois: Human Kinetics; 1995:155–183.

21. Stelmach GE, Worringham CJ. Sensorimotor deficits related to postural stability. Implications for falling in the elderly. Clin. Geriatr. Med. 1985, 1(3):679-94.

22. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N. Engl. J. Med. 1988, 29(26):1701-7.

23. Mulder T, Zijlstra W, Geurts A. Assessment of motor recovery and decline. Gait Posture. 2002, 16(2):198-210.

24. Wickens CD. Processing resources in attention: Varieties of Attention. Parasuraman R, Davies DR (Ed.). Orlando: Academic Press; 1984: 63–102.

25. de Visser E, Veth RP, Schreuder HW, Duysens J, Mulder T. Reorganization of gait after limb-saving surgery of the lower limb. Am J Phys Med Rehabil. 2003, 82:825-31

26. Huitema RB, Hof AL, Mulder T, Brouwer WH, Dekker R, Postema K. Functional recovery of gait and joint kinematics after right hemispheric stroke. Arch Phys Med Rehabil. 2004, 85(12):1982-8.

27. Bergland A, Pettersen AM, Laake K. Falls reported among elderly Norwegians living at home. Physiother Res Int. 1998, 3(3): 164-74.

28. Moe-Nilssen R, Nordin E, Lundin-Olsson L; Work Package 3 of European Community Research Network Prevention of Falls Network Europe. Criteria for evaluation of measurement properties of clinical balance measures for use in fall prevention studies. J Eval Clin Pract. 2008 Apr, 14(2):236-40.

29. Lamb SE, Jørstad-Stein EC, Hauer K, Becker C; Prevention of Falls Network Europe and Outcomes Consensus Group. Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. J Am Geriatr Soc. 2006 May, 54(5):865.

30. Gibson MJ, Andres RO, Isaacs B, Radebaugh T, Worm-Petersen J. The prevention of falls in later life. A report of the Kelloggs International Work Group. Danish Medical Bulletin 1987, 34 (4): 1-24

31. AMTI Balance Clinic (2001) Users Manual Version 1.1

32. Le Clair K, Riach C. Postural stability measures: what to measure and for how long. Clin Biomech. 1996, 11(3):176-178.

33. Jamet M, Deviterne D, Gauchard GC, Vancon G, Perrin PP. Age-related part taken by attentional cognitive processes in standing postural control in a dual-task context. Gait Posture. 2007, 25(2):179-84.

34. Pajala S, Era P, Koskenvuo M, Kaprio J, Tolvanen A, Rantanen T.Genetic and environmental contribution to postural balance of older women in single and dual task situations. Neurobiol Aging. 2007, 28(6):947-54

35. Pellecchia GL. Dual-task training reduces impact of cognitive task on postural sway. J Mot Behav. 2005, 37(3):239-46

36. Andersson G, Hagman J, Talianzadeh R, Svedberg A, Larsen HC. Effect of cognitive load on postural control. Brain Res. Bull. 2002, 58(1): 135-9.

37. Lezak M.D: Neuropsychological assessment (4th ed.), New York: Oxford University Press; 2004.

38. de Vet HCW, Terwee CB, Knol DL, Bouter LM. When to use agreement versus reliability measures. J Clin Epidemiol. 2006, 59 (10): 1033-9

39. Smidt N, van der Windt DA, Assendelft WJ, Mourits AJ, Deville WL, de Winter AF, Bouter LM. Interobserver reproducibility of the assessment of severity of complaints, grip strength, and pressure pain threshold in patients with lateral epicondylitis. Arch Phys Med Rehabil. 2002, 83:1145–1150.

40. Streiner DL, Norman GR. Health measurement scales: A practical guide to their development and use (3rd ed.) Oxford: Oxford University Press; 2003.

41. Portney, L.G. and Watkins, M.P. Foundations of Clinical Research. Applications to Practice. Norwalk: Appleton & Lange; 1993.

42. Shrout, PE, Fleiss JL. Intraclass correlation: uses in assessing rater reliability. Psychological Bulletin, 1979, 86:420-428

43. Roebroeck ME, Harlaar J, Lankhorst GJ. The application of generalizability theory to r eliability assessment: an illustration using isometric force measurements. Phys Ther. 1993, 73:386–395.

44. Stratford P. Reliability: consistency of differentiating among subjects (letter). Phys Ther 1996, 28:299-300

45. Bland JM and Altman DG, Statistical methods for assessing agreement between two methods of clinical measurement, Lancet 1986, 327: 307–310.

46. Day BL, Steiger MJ, Thompson PD, Marsden CD. Effect of vision and stance width on human body motion when standing: implications for afferent control of lateral sway. J Physiol. 1993 Sep, 469:479-99.

47. Sims KJ, Brauer SG. A rapid upward step challenges medio-lateral postural stability. Gait Posture. 2000 Dec, 12(3):217-24.

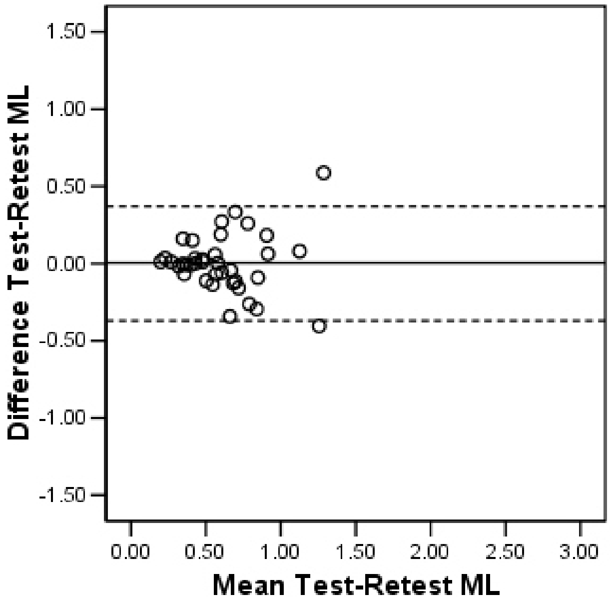
48. Kirby RL, Price NA, MacLeod DA. The influence of foot position on standing balance. J Biomech 1987, 20:423–7.

49. Chiari L, Rocchi L, Cappello A. Stabilometric parameters are affected by anthropometry and foot placement. Clin Biomech. 2002 Nov-Dec, 17(9-10):666-77.

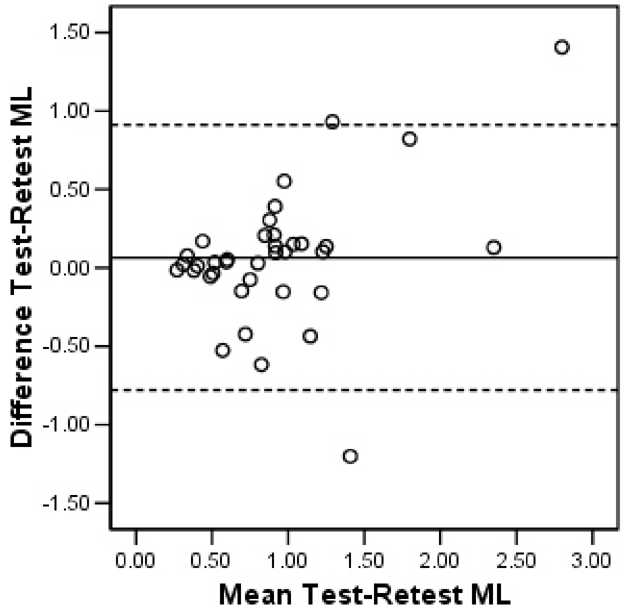
Appendix 1

Figure 1.
Bland and Altman plots of the maximal displacement in medial-lateral direction (ML) in single and dual-task conditions, with and without vision.

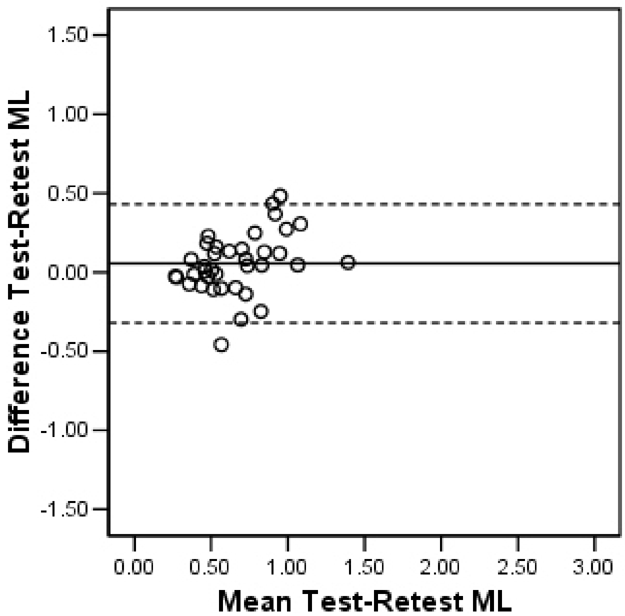
a) Single task with vision



b) Dual task with vision



c) Single task no vision



d) Dual task no vision

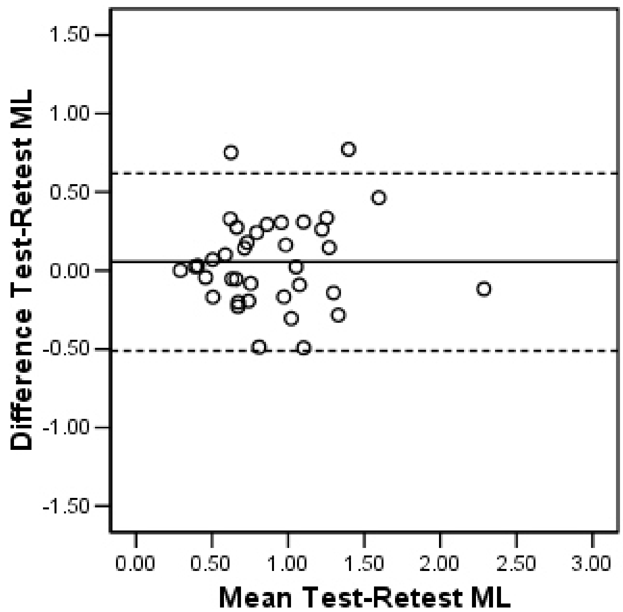
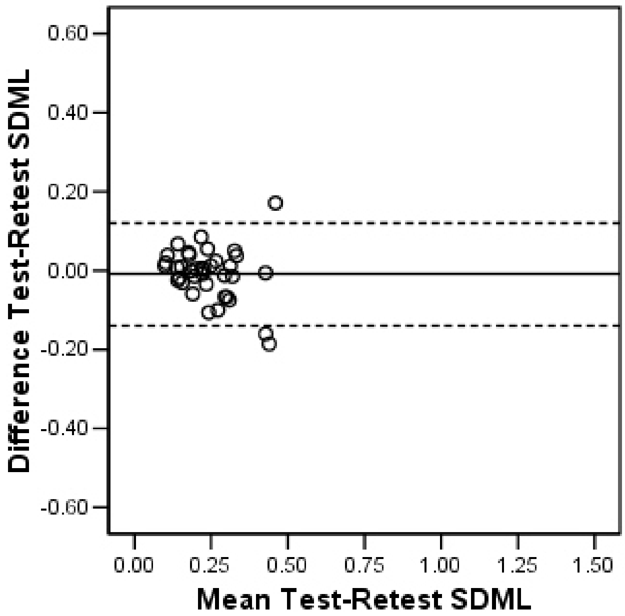
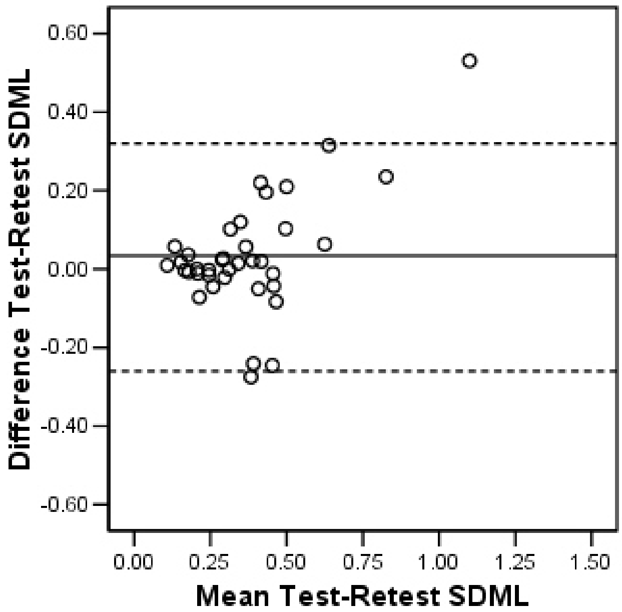


Figure 2.
Bland and Altman plots of the root mean square of the maximal displacement in medial-lateral direction (SDML) in single and dual-task conditions, with and without vision.

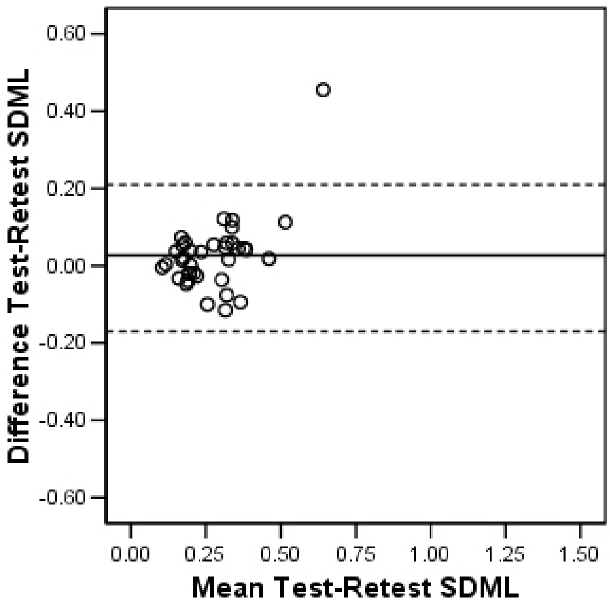
a) Single task with vision



b) Dual task with vision



c) Single task no vision



d) Dual task no vision

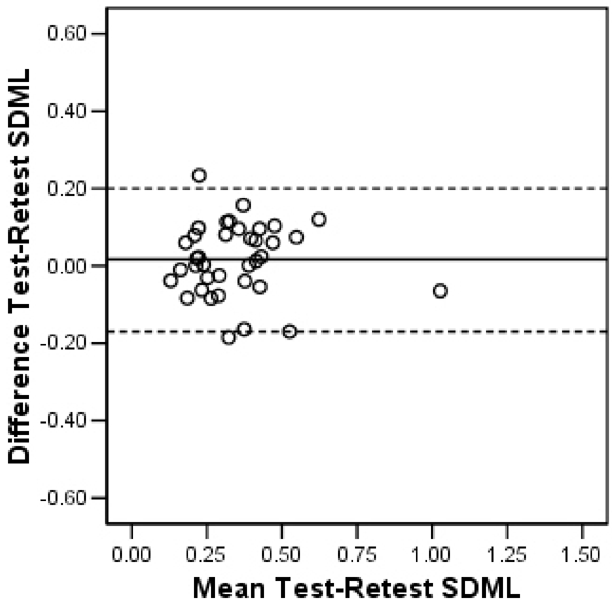
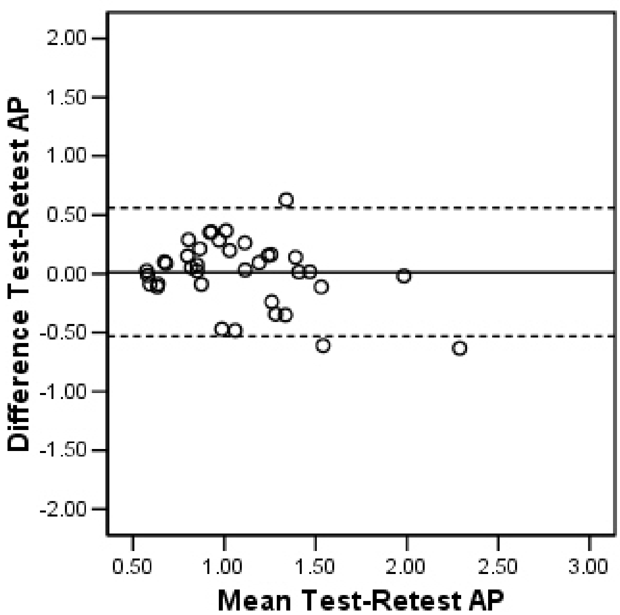
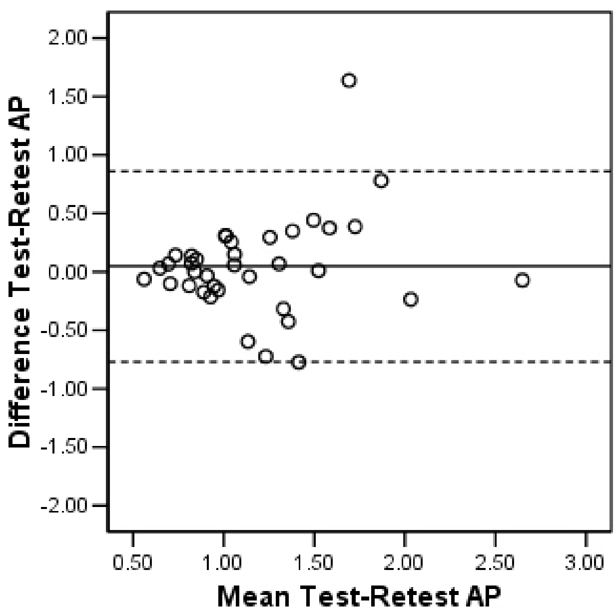


Figure 3.
Bland and Altman plots of the maximal displacement in anterior-posterior direction (AP) in single and dual-task conditions, with and without vision.

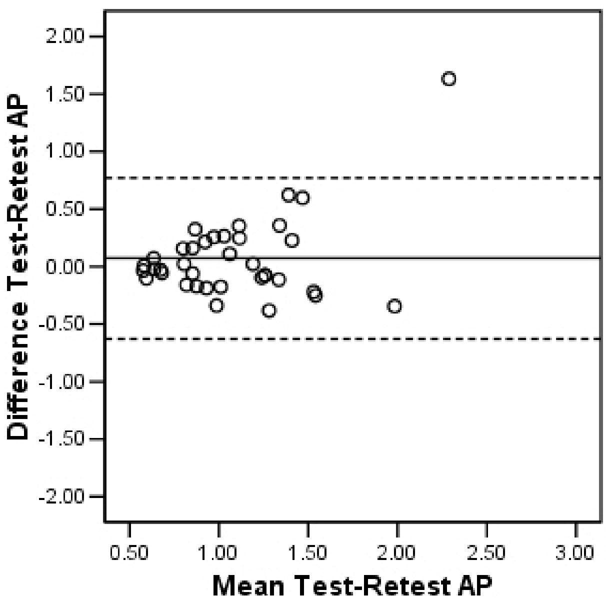
a) Single task with vision



b) Dual task with vision



c) Single task no vision



d) Dual task no vision

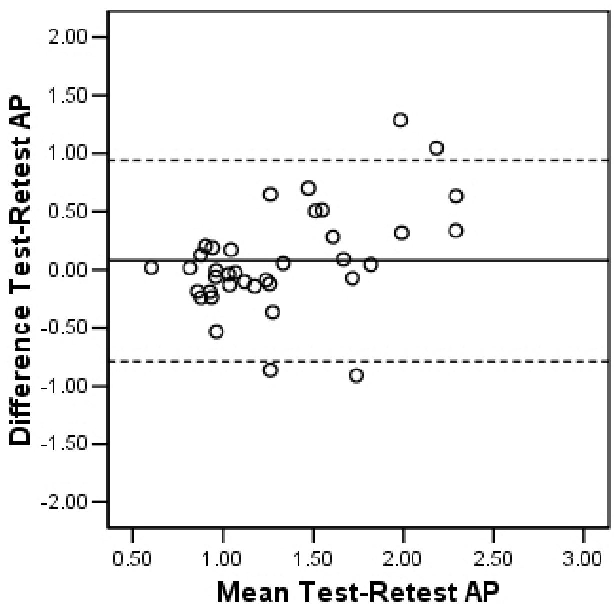
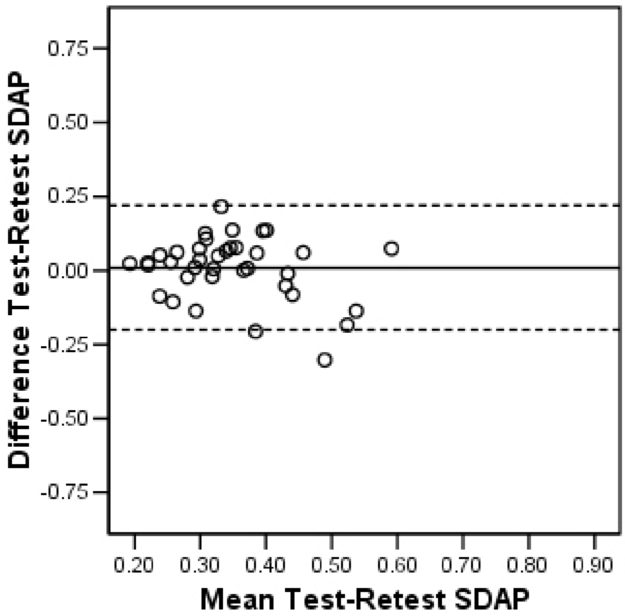
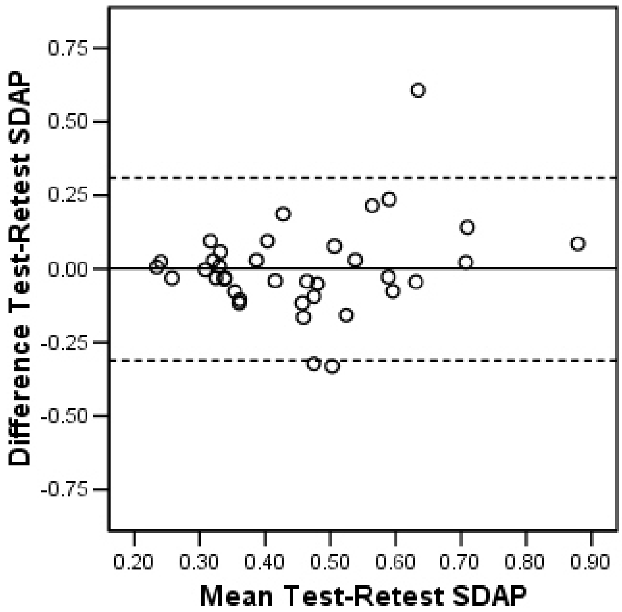


Figure 4.
Bland and Altman plots of the root mean square of the maximal displacement in anterior-posterior direction (SDAP) in single and dual-task conditions, with and without vision.

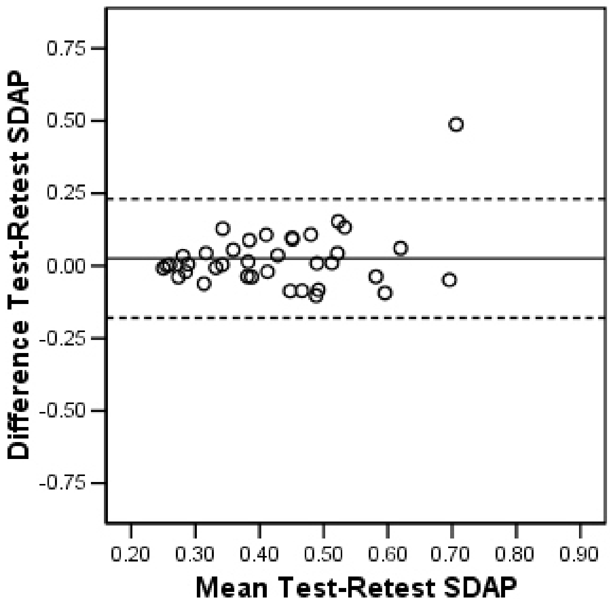
a) Single task with vision



b) Dual task with vision



c) Single task no vision



d) Dual task no vision

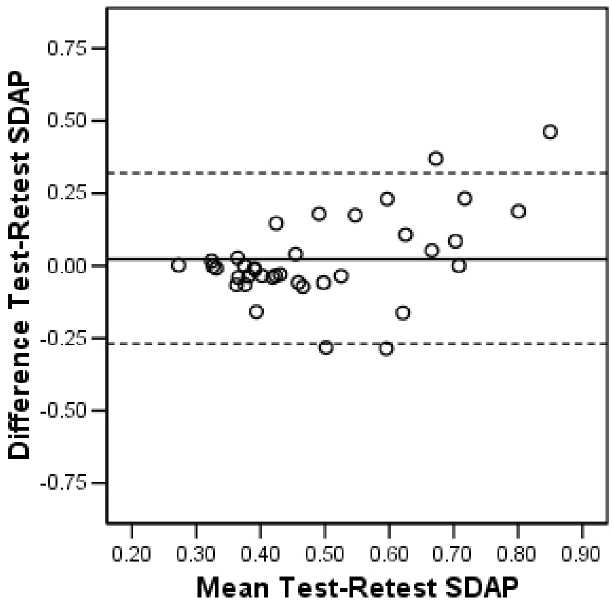
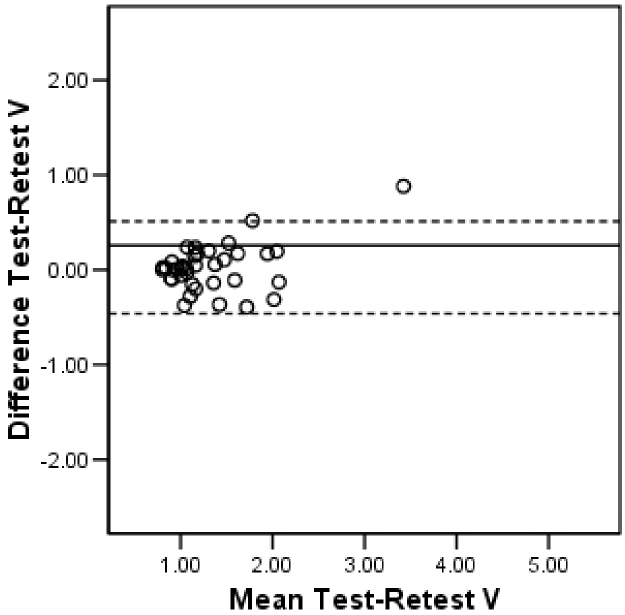
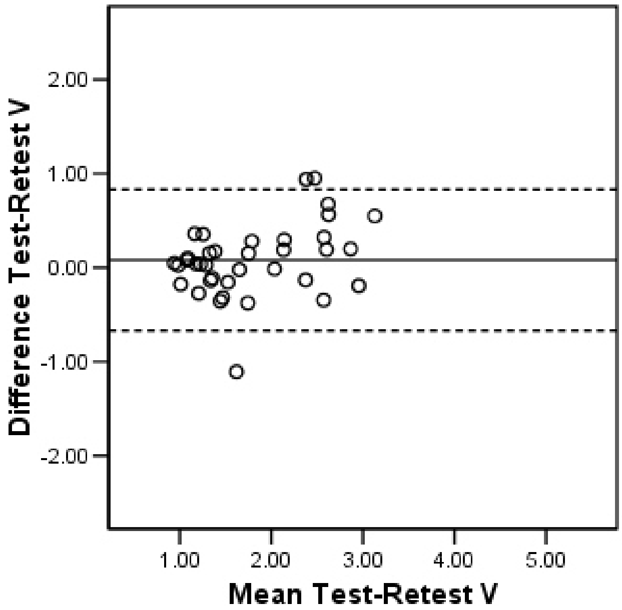


Figure 5.
Bland and Altman plots of the average speed of displacement (V) in single and dual-task conditions, with and without vision.

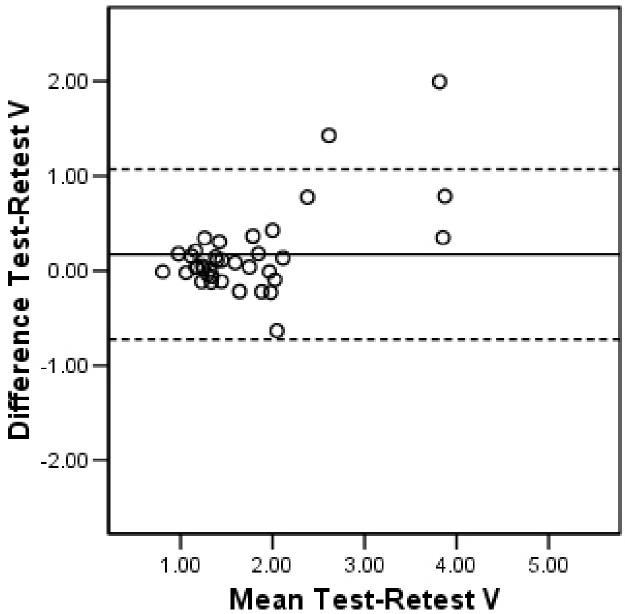
a) Single task with vision



b) Dual task with vision



c) Single task no vision



d) Dual task no vision

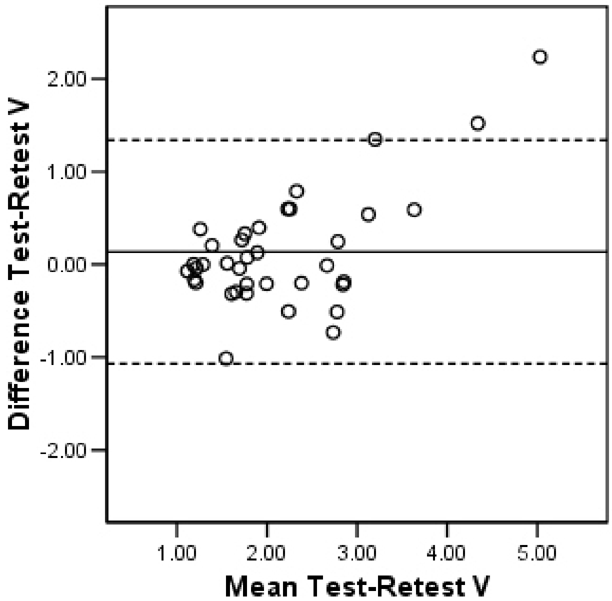
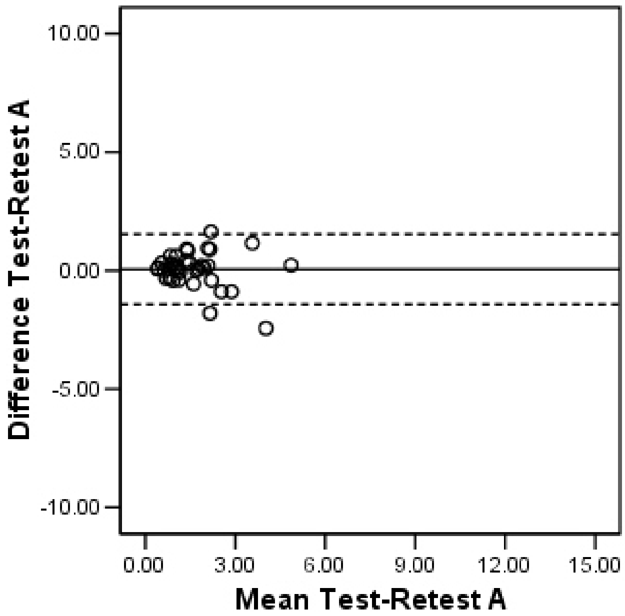
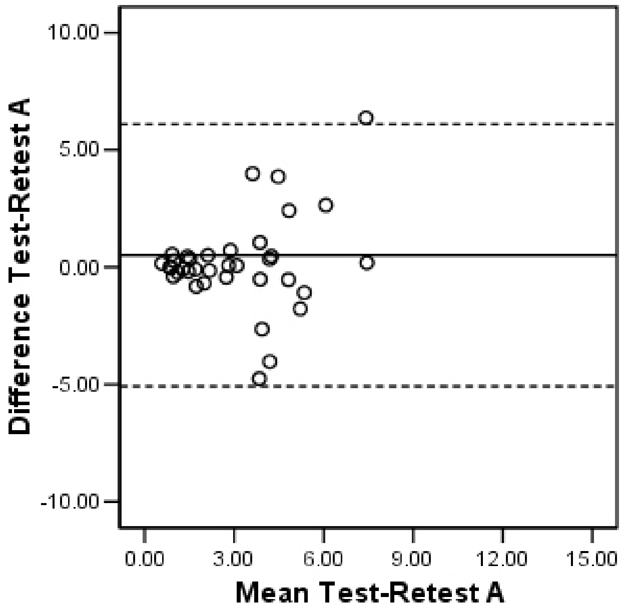


Figure 6.
Bland and Altman plots of the area of the 95th percentile ellipse (AoE) in single and dual-task conditions, with and without vision.

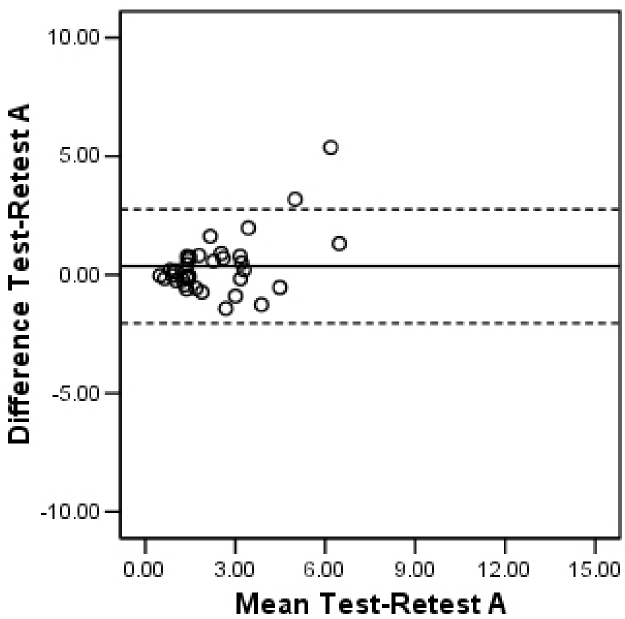
a) Single task with vision



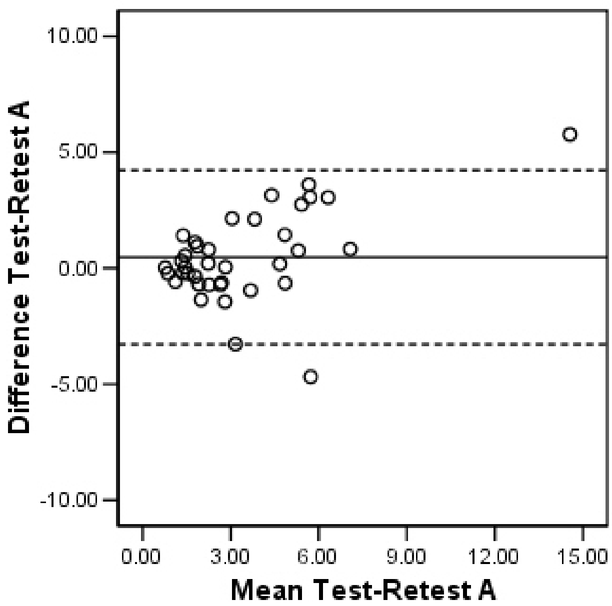
b) Dual task with vision



c) Single task no vision



d) Dual task no vision



Chapter 5

Fall Prediction in the Elderly; A 1 year prospective study

Jaap Swanenburg
Eling D. de Bruin
Daniel Uebelhart
Theo Mulder

In Press Gait and Posture 2010

Abstract

The aim of the present study was to determine whether force platform variables in single and dual task situations are able to predict the risk of multiple falls in a community-dwelling elderly population. Two hundred seventy elderly persons (225 female, 45 male; age, 73 ± 7 years) performed balance assessment with and without vision. Seven force platform variables were assessed to predict the risk of multiple falls; maximum displacement in the anteroposterior and medial–lateral directions (Max-AP, Max-ML), mean displacement in the medial–lateral direction (MML), the root mean square amplitude in anteroposterior and medial–lateral directions (RMS-AP, RMS-ML), the average speed of displacement (V), and the area of the 95th percentile ellipse (AoE). Falls were prospectively recorded during the following year. A total of 437 registered falls occurred during monitoring period. The force platform variable RMS-ML in the single-task condition (odds ratio, 21.8) predicts multiple falls together with the following covariables: history of multiple falls (odds ratio, 5.6), use of medications (fall risk medications or multiple medicine use; odds ratio, 2.3), and gender (odds ratio, 0.34). Multiple fallers assumed a different stance width than non-fallers.

The force platform variable RMS-ML predicts fall risk in women with a history of multiple falls who take fall-risk medications or use multiple medicines. Multiple fallers position themselves with a narrower stance than non-fallers during measurement.

Chapter 6

Dual tasking under compromised visual and somatosensory input in the elderly.

Jaap Swanenburg
Eling D. de Bruin
Stefan Hegemann
Daniel Uebelhart
Theo Mulder

Submitted: BMC Geriatrics 2009

Abstract

Background: The aim was to determine postural balance change caused by no-vision and/or compromised somatosensory information in single and dual tasking, and to determine the (change in) dual-task costs caused by the reduction of combined sensory input. ***Methods:*** Fifteen independently living elderly persons (age, 77.5 ± 7 years) were analyzed by means of a force plate. variables assessed were maximum displacement and standard deviation amplitude in the medial–lateral and anterior–posterior direction, average speed of displacement, and the area of the 95th percentile ellipse per given time. The dual-task costs were calculated for posture and cognitive performance. ***Results:*** Fractional analysis of variance showed a significant effect between the single- and dual-task situations in medial–lateral (F[1/104] = 18.158, $p < 0.001$), standard deviation medial–lateral (F[1/104] = 19.855, $p < 0.001$), anterior–posterior (F[1/104] = 15.984, $p < 0.001$), standard deviation anterior–posterior (F[1/104] = 14.415, $p < 0.001$), average speed of displacement (F[1/104] = 10.316, $p < 0.001$), and area of the 95th percentile ellipse (F[1/104] = 15.939, $p < 0.001$). One-way analysis of variance showed significant differences in change scores between single and dual tasking and dual-task costs between the reference situation and the combined "no-vision–reduced somatosensory" situation. There were no differences between multiple fallers/ non-fallers or different situations in cognitive performance. ***Conclusion:*** The findings refute both the theoretical framework of resource-sharing and the adaptive resource-sharing theory, therefore seeming to provide support for the theory of an increased processing area. Future study should focus on assessing the processing area during a combined reduction of sensory input situation to test this assumption.

Chapter 7

Epilogue, Novel aspects of force platform postural balance measures in the elderly

The first objective of this thesis was to examine a physical intervention program that aimed to determine the risk of falling in a population of elderly persons with osteoporosis. The results of this intervention program (Chapter 2) led, among others, to a reconsideration of the measurement protocol for postural balance assessment. Less falls and a reduced risk of falling within the intervention group were observed based on fall screening interviews. However, no changes in postural balance variables were identified by the force platform. Based on this seemingly contradictory result, the following questions were raised: (1) was the measurement protocol for postural balance assessment challenging and specific enough to detect balance deficits? (2) Are postural balance tests with a force platform sensitive enough? (3) Are these force platform test protocols able to predict any falls?

These questions led to a new postural balance measurement protocol. Of particular interest was the question whether the new postural balance measurement protocol would be able to detect differences between fallers and nonfallers. Furthermore, the reliability of the measurement itself and the ability to predict falls were topics for further methodological consideration. An important part of the new protocol was the use of dual-task test paradigms. This aspect was added with the intention to mimic a more realistic “real-life” measurement environment in a clinical setting.

Which force platform variable should we pick?

A general testing of all possible fall–relevant force platform variables was needed to gain a better overview. Almost all tested balance variables showed a significant difference between fallers and nonfallers. An important novel aspect that is discussed in this thesis is the reliability testing of postural balance measures in elderly fallers and nonfallers. Additionally for gaining a better insight on the performance of measuring a force platform variable, both reliability and agreement parameters were calculated. The good results in reliability, agreement parameters and the observed differences between fallers and nonfallers showed the relevance of including symptomatic populations in a fall study as previous suggested[1] and indicated the potential value of force platform assessments in older populations with postural balance impairments (Chapter 4).

Dual tasking

Additional tasks that are assumed to disturb standing postural control can be divided into motor and cognitive tasks. The findings in Chapter 3 suggest that the combined articulation and attention-demanding secondary task (counting backward aloud) stressed the attentional system of the elderly to such an extent that it compromised the performance of the primary task (quiet standing). Therefore, the counting backward aloud task may be used as a dual task for clinical balance assessment in at-risk populations.

Using the combined articulation and attention-demanding task as a secondary task required a confirmation of the reliability of the new measurement protocol. The findings in Chapter 4 showed that the new measurement protocol could be reproduced in a clinical setting. For the first time, the force platform measurement protocol was tested under this aspect in both single- and dual-task situations. The agreement parameters of the force platform measures were even better under dual tasking than under a single-task situation. Additionally, there were no systematic measuring errors in both single-task and dual-task conditions in a group of elderly fallers and nonfallers. The new measurement protocol is, therefore, a reliable measurement procedure, for example, to assess the effects of physical exercise in elderly persons with balance impairments.

Nevertheless the dual tasking did not offer any extra value to the prediction of future falls in elderly fallers and non-fallers. A further important aspect of this thesis, namely, was the determination of the predictive value for future falls of the force platform measures. In a review these variables were discussed as being unclear[2]. Chapter 5 describes a prospective study in which older individuals were followed for 1 year following balance assessment. Only the root-mean-square amplitude in the medial–lateral direction showed a predictive value in a female population with a history of falling and taking multiple medications.

In summary, all variables tested with our measurement protocol were able to detect differences between fallers and nonfallers, but only root-mean-square amplitude in a medial–lateral direction showed a predictive value in the aforementioned population. Only one force platform variable under a single tasking test situation has predictive value in a specific group of elderly (Chapter 5).

Chapter 6 describes another novel aspect that emerged when testing the influence of dual tasking on postural balance in a combined non-vision situation and a reduced somatosensory situation (Chapter 6). The combined reduction of sensory input (vision and compromised somatosensory) resulted in a decrease of dual-task costs for posture with at the same time no change in dual-task costs for cognition. This result refutes the often used theoretical framework of resource-sharing[3] and the adaptive resource-sharing theory[4]. The findings, therefore, seem to provide support for the theory of an increased processing area in the brain[5]. This theory believes that the brain regions active for dual-task conditions highly overlap with regions found to be active for each of the single tasks and that the brain areas simply increase in magnitude with greater processing demands (Erickson et al. 2005). The combined reduction of sensory input could have led the participants to greater processing area and therefore let them to generate more cognitive capacity. This increased cognitive capacity could hence be used to compensate for the sensory input reduction and for the cognitive task as well, which would explain the reduced dual-task costs for posture and absolute difference of sway in dual- and single-tasking situations.

Other new aspects of postural balance measures

An intriguing observation was made regarding the comfortable standing position that the participants took on the force platform when their balance was assessed. Multiple fallers and nonmultiple fallers exhibited a different comfortable standing position. The preferred stance width and the ratio (base of support width/hip width) showed a significant difference between multiple fallers and nonmultiple fallers in the group between 60 and 75 years old. Multiple fallers took a narrower stance width position compared with nonmultiple fallers. A narrower stance width in multiple fallers could be a significant sign because it may indicate a decrease in stability.

Recommendations for future research: focusing on clinical decision-making

The results of this thesis indicate that future research should be conducted with force platform measures to determine the effectiveness of intervention programs, and should be focused on fall prevention in a female population with a history of falling who take fall-risk medications or use multiple medications. Further research should also be conducted to investigate the dual-task costs in fallers and nonfallers. Larger test populations and maybe different clinical populations should be analyzed in different sensory-reduced situations. Other recommendations for further research include continuing to explore the different standing strategies between multiple fallers and nonmultiple fallers.

To obtain the diagnostic information of the force platform alone, the outcomes of all other diagnostic tests in use must be known as well, which necessitates the concurrent assessment of clinical diagnostic assessments, clinical balance tests besides measurements with a force platform. Therefore, in future research, larger samples of measurements in fall subpopulations with various diagnostic methods are needed.

The force platform method as presented in this thesis does not yet appear successful for interpreting the measurement results of a test explicitly related to the risk of falls. Based on the presented data from a force platform test protocol of an older adult group containing both fallers and nonfallers in relation to a categorization of test values (Chapter 5), no conditional relationship between the force platform measurements and group categorization has been found. We did focus on several specific parameters, namely the maximum displacement in the anteroposterior and medial–lateral direction, mean displacement in the medial–lateral direction, the root-mean-square amplitude in anteroposterior and medial–lateral directions, the average speed of displacement, and the area of the 95th percentile ellipse. Measurements of these parameters are only one factor to determine postural control.

In a next assessment phase, the validity of force platform assessments in clinical populations should be studied. Furthermore, questions of therapeutic efficacy (Did intervention or patient (faller) management change?), patient outcome efficacy (Did quality of life improve?), and, if possible, social efficacy (Are costs acceptable for society?) should be answered[6].

Guyatt et al. (1986) presented a framework for the clinical evaluation of diagnostic technology assessment in the future. Depending on the point of view, there are a number of criteria that has to be fulfilled before we can conclude that a diagnostic technology is ready for dissemination. These criteria can be considered to form a hierarchy of progressively more rigorous evaluation as follows:

- *Technologic capability*: The technology provides the instruments with the capability to perform measurements;
- *Range of possible uses*: The technology promises to provide important diagnostic information in a number of clinical situations;
- *Diagnostic accuracy*: The technology provides information that allows healthcare workers to make a more accurate assessment regarding the presence and severity of disease;
- *Impact on healthcare providers*: The technology allows healthcare workers to be more confident of their diagnoses and thereby decreases their anxiety and increases their comfort;
- *Therapeutic impact*: The therapeutic decisions made by healthcare providers are altered as a result of application of the technology; and
- *Patient outcome*: Application of the technology results in benefit to the patient[7].

Conclusion

Falls are a serious problem among aged adults. The population of older adults continues to grow, the consequences of falling has and will have a growing impact on society. In terms of efficient fall prevention it is essential to identify the people at risk for falls before the first incident. This thesis examined one of the factors which are assumed to be causally related to falling: postural balance. Force platform data from various environmental conditions and additional task situations indicate that the force platform method provides reliable data on the quality of upright posture control. Force platform–based measures differentiate postural control between fallers and non-fallers. Force platform measures have previously been considered to best predict risk for recurrent falls; we can confirm this hypothesis, but only in a female population with a history of falling and using multiple medications. Future research should continue to address the causes of falls with the goal reduce the falls and its consequences.

References

1. Hoving JL, Pool JJ, van Mameren H, Devillé WJ, Assendelft WJ, de Vet HC, de Winter AF, Koes BW, Bouter LM. Reproducibility of cervical range of motion in patients with neck pain. BMC Musculoskelet Disord. 2005; 136:59.

2. Zijlstra A, Ufkes T, Skelton DA, Lundin-Olsson L, Zijlstra W: Do dual tasks have an added value over single tasks for balance assessment in fall prevention programs? A mini-review. Gerontology 2008; 54: 40–49.

3. Woollacott M, Shumway-Cook A: Attention and the control of posture and gait: A review of an emerging area of research. Gait Posture 2002; 16:1–14.

4. Mitra S. Adaptive utilization of optical variables during postural and suprapostural dual-task performance: Comment on Stoffregen, Smart, Bardy, and Pagulayan (1999). J Exp Psychol Hum Percept Perform 2004; 30:28–38.

5. Erickson KI, Colcombe SJ, Wadhwa R, Bherer L, Peterson MS, Scalf PE, Kramer AF. Neural correlates of dual-task performance after minimizing task-preparation. Neuroimage 2005; 28:967–979.

6. van der Schouw YT, Verbeek ALM, Ruijs SHJ. Guidelines for the assessment of new diagnostic tests. Invest Radiol. 1995; 30:334–340.

7. Guyatt GH, Tugwell PX, Feeny DH, Haynes RB, Drummond M. A framework for clinical evaluation of diagnostic technologies. Can Med Assoc J. 1986; 134:587–594.

Summary

Summary

At first in this thesis, an intervention programme was tested for the effect on the risk of falling in a population of elderly. The aim of the study was to investigate if exercise, combined with protein intake and calcium/vitamin D supplementation would have a larger effect on the risk of falling and postural balance outcomes than calcium/vitamin D supplementation only. An observational performance test (risk of falling) and performance measurements (force platform) were used as outcome measures.

The results of this study were a reduced risk of falling and less falls within the intervention group but no change of variables of the force platform. Based on this contrary result, the following questions were raised:

a) Was the test postural balance measurement protocol not challenging enough to detect any balance deficits?
b) Are force platform test sensitive enough to detect any change - in a normal and in a challenging situation?
c) Are these force platform test protocols able to predict any fall - in a normal and in a challenging situation?
d) What is the relation of postural stability and challenging measurement environment?

The postural balance measurement environment in Chapter 2 could have been too simple for most elderly to detect any differences between fallers and non-fallers. Would an additional task change the measurement environment in such a way to detect any differences? Which dual task would be the most appropriate? The additional task should have the most disturbing influence on fall-related force platform variables. Therefore, it should be possible to carry out the additional test (dual task) in a non-vision situation. Attention-demanding secondary tasks have shown deleterious effects on postural control in older adults[1]. One of these additional tasks is the counting backwards task. This task would meet with the requirements of disturbing balance and being executed in a non-vision

situation[2-4]. Until now, the influence of this task on postural stability has only been tested on healthy young volunteers[5]. They concluded that disturbances of counting backwards in postural control were caused by the vocal articulation of counting and not by the competing demands for attention[5]. In Chapter 3, an analysis of the results of Yardley and colleagues (1999) has been undertaken. Are the disturbances in postural control under dual-task conditions in elderly caused mainly by the additional motor effect of articulation (speaking aloud), or by the effect of an additional cognitive component of a task, or by a combination of the two? Furthermore, it was investigated whether differences exist between fallers and non-fallers in terms of disturbance of postural control under the different additional tasks. The findings suggest that the combined articulation and attention-demanding secondary task stressed the attentional system of elderly to such an extent that it compromised the performance of the primary task (quite standing). The counting backwards aloud task may be used as a dual task for clinical balance assessment in populations at risk of falling. This task was best able to disturb postural control.

The second question dealt with in Chapter 2 described question whether force platform tests are sensitive enough to detect any change. Although the reliability of fore plate's measurement was determined in different studies, the dual tasking aspect was not taken into account. In addition, most of the reliability studies tested healthy people[6-8]. Until now, no reliability studies that included fallers have been reported. However, since one-third of community-dwelling people over 65 years of age experience one or more falls each year, it is important to include elderly fallers in reliability studies[9-13]. In Chapter 4 a study is described with how the interrater and test-retest reliability of force platform variables were tested. The variables tested were those which seemed to be the most appropriate to detect possible fallers and non-fallers. These variables were tested under single and dual-task conditions, with and without vision. This study showed good reliability results for group assessment and no systematic errors of the measurement protocol in measuring postural balance in the elderly in a single-task and dual-task condition.

The selection of posturography-derived parameters that discriminate between elderly fallers and nonfallers is shown to be inconclusive[14]. Next to the discrimination between elderly faller, an important goal of postural balance measures is the prediction of future falls with help of a forceplate. Piirtola and Era (2006) argued that the reason for not being able to predict future falls is related to the lack of studies in which a prospective design is used and that records falls as the primary outcome[15]. Therefore, more prospective fall assessment studies are needed that use posturography. A systematic evaluation of a balance with "complex conditions "protocol is needed to determine which posturography-derived balance variable is most associated with future falls. In their review, Zijlstra and colleagues (2008) showed that 2 studies provide some evidence that measurements with a dual task protocol could add some value for the prediction of falls. They recommended future studies with large sample size should investigate whether an overall performance score that combines the scores of the cognitive and balance task is more sensitive for predicting falls or detecting changes in balance performance than the individual balance or cognitive task score during dual-task performance[16]. In Chapter 5, a prospective study with 270 participants is described. The aim of this study was to determine whether postural balance variables measured with a forceplate with or without challenging conditions were able to prospectively predict fallers and non-fallers in a community-dwelling elderly population over a 12-month period. The challenging conditions applied were reduced vision and/or dual cognitive tasks. The findings show that the force platform variable RMS-ML (root-mean-square amplitude in medial-lateral directions) predicts future fall risk in women with a history of multiple falls who take fall-risk medications or use multiple medicines. Multiple fallers were also shown to position themselves with a narrower stance during balance testing.

The aim in Chapter 6 was to firstly determine postural balance changes caused by no-vision, compromised somatosensory information and a combination of no-vision and reduced somatosensory information in both single and dual tasking. Secondly, the aim was to determine the dual task costs (DTC) and the DTC change caused by the different test conditions. The combined reduction of sensory input (vision and compromised somatosensory) resulted in a decrease of dual-task costs for posture with at the same time no change in dual-task costs for cognition. This result refutes the often used theoretical framework of resource-sharing[1] and the adaptive resource-sharing theory[17]. The findings, therefore, seem to provide support for the theory of an increased processing area[18]. The theory believes that the brain regions active for dual-task conditions highly overlap with regions found to be active for each of the single tasks and that the brain areas simply increase in magnitude with greater processing demands[18] . The combined reduction of sensory input could have led the participants to greater processing area and therefore let them to generate more cognitive capacity. This increased cognitive capacity could hence be used to compensate for the sensory input reduction and for the cognitive task as well, which would explain the reduced dual-task costs for posture and absolute difference of sway in dual- and single-tasking situations.

In conclusion, this thesis showed new aspects of force platform measurements of elderly fallers and non-fallers. Future research could be conducted with force platform measurements to determine the effectiveness of intervention programmes, focused on fall prevention.

Samenvatting

Samenvatting

Allereerst werd in deze scriptie een interventieprogramma getest over het effect op het risico voor vallen bij een populatie van ouderen. Het doel van het onderzoek was te onderzoeken of lichaamsbeweging gecombineerd met het innemen van proteïne en calcium/vitamine D-supplementen een hoger effect zou hebben op het risico van vallen en op houdingsbalans dan het alleen innemen van calcium/vitamine D-supplementen. Als resultaatmetingen werden een observationele prestatietest (risico op vallen) en prestatiemetingen (krachtenplatform) gebruikt .

Uit de resultaten van dit onderzoek bleken er een verminderd risico op vallen en minder valpartijen in de interventiegroep te zijn, maar er trad geen verandering van de variabelen in houdingsbalans van het krachtenplatform op. Op basis van dit tegengestelde resultaat werden de volgende vragen opgesteld:

e) Was het meetprotocol voor het testen van de houdingsbalans niet uitdagend genoeg om elk gebrek aan balans te meten?

f) Zijn testen met het krachtenplatform gevoelig genoeg om elke verandering op te sporen - in een normale en in een uitdagende situatie?

g) Zijn deze testprotocollen met het krachtenplatform in staat elke val te voorspellen - in een normale en in een uitdagende situatie?

h) Wat is de relatie tussen houdingsstabiliteit en een uitdagende meetomgeving?

De meetomgeving voor houdingsbalans in Hoofdstuk 2 zou voor de meeste ouderen wel eens te eenvoudig geweest kunnen zijn om eventuele verschillen tussen vallers en niet-vallers op te sporen. Zou een aanvullende taak de meetomgeving zodanig veranderen dat eventuele verschillen opgespoord kunnen worden? Welke dubbele taak zou het meest geschikt zijn? De aanvullende taak zou de meest verstorende invloed moeten hebben op aan vallen gerelateerde houdingsbalansvariabelen. Het moet om die reden mogelijk zijn de aanvullende test (dubbele taak) in een situatie uit te voeren waarbij geen visus nodig is. Het is aangetoond dat secundaire taken

waarbij de aandacht nodig is, verstorende effecten hebben op de houdingscontrole bij oudere volwassenen[1]. Een van deze aanvullende taken is achteruit tellen. Deze taak zou voldoen aan de bepalingen van een verstoring van de balans en kan uitgevoerd worden in een situatie waarin geen visus nodig is[2-4]. Tot nu toe is de invloed van deze taak op de houdingsstabiliteit alleen onderzocht bij gezonde jonge vrijwilligers[5]. De onderzoekers kwamen tot de conclusie dat verstoring van de houdingscontrole door achteruit tellen veroorzaakt werd door het vocaal articuleren van het tellen en niet door de concurrerende vragen om aandacht[5]. In Hoofdstuk 3 is een analyse van de resultaten van Yardley en collega's (1999) uitgevoerd. Worden de verstoringen van de houdingscontrole tijdens situaties met een dubbele taak bij ouderen voornamelijk veroorzaakt door het aanvullende motoreffect van articulatie (hardop praten) of door het effect van een aanvullende cognitieve component van een taak of door een combinatie van die twee? Bovendien werd onderzocht of er verschillen zijn tussen vallers en niet-vallers in termen van verstoring van de houdingscontrole tijdens de verschillende aanvullende taken. De bevindingen suggereren dat het gecombineerde hardop praten en de aandachtvragende secundaire taak het aandachtssysteem van oudere mensen dermate onder druk zet dat het de prestatie bij de primaire taak (rechtop staan) in gevaar bracht. De taak van hardop achteruit tellen zou gebruikt kunnen worden als een dubbele taak voor het klinisch bepalen van de balans bij populaties die een risico op vallen hebben. Deze taak was het beste in staat om de houdingscontrole te verstoren.

De tweede vraag die in Hoofdstuk 2 behandeld werd, beschreef de vraag of krachtenplatform tests voor houdingsbalans gevoelig genoeg waren om alle veranderingen op te sporen. Hoewel de betrouwbaarheid van meting door middel van het krachtenplatform in diverse studies vastgesteld werd, werd daarbij geen rekening gehouden met het aspect van dubbele taken. Bovendien werden er bij het merendeel van de betrouwbaarheidsstudies gezonde proefpersonen onderzocht[6-8]. Tot nu toe waren er geen betrouwbaarheidsstudies waarin vallers waren opgenomen. Maar omdat een derde van de zelfstandig wonende mensen boven de 65 jaar elk jaar een of meer keer valt, is het belangrijk om in betrouwbaarheidsstudies ook oudere vallers op te nemen[9-13]. In Hoofdstuk 4 is een studie beschreven over hoe de interrater- en test-hertestbetrouwbaarheid van de variabelen van krachtenplatform onderzocht werden. De geteste variabelen waren de variablen die het meest van toepassing leken om mogelijke vallers en niet-vallers op te sporen. Deze variabelen werden onderzocht onder omstandigheden met een enkele taak en met een dubbele taak, waarvoor wel en geen visus nodig was. Dit onderzoek toonde goede betrouwbaarheidsresultaten aan voor groepsbepaling en liet geen systematische fouten in het meetprotocol zien voor het meten van houdingsbalans bij ouderen in omstandigheden met een enkele taak en met een dubbele taak.

Er wordt aangetoond dat de selectie van uit posturografie afgeleide parameters, die onderscheid maken tussen oudere vallers en niet-vallers, niet overtuigend zijn[14]. Naast het onderscheid tussen oudere vallers is een belangrijke doelstelling van het meten van houdingsbalans het voorspellen van vallen in de toekomst met behulp van een krachtenplatform. Piirtola en Era (2006) stelden dat de reden voor het niet in staat zijn om vallen in de toekomst te voorspellen, gerelateerd is aan het gebrek aan onderzoeken waarin een prospectief ontwerp gebruikt wordt en waarin valpartijen als het primaire resultaat genoteerd worden[15]. Er zijn daarom meer prospectieve onderzoeken naar vallen nodig waarin posturografie gebruikt wordt. Een systematische evaluatie van een balans met een protocol voor 'complexe omstandigheden' is noodzakelijk om te bepalen welke uit posturografie afgeleide balansvariabele het meest gepaard gaat met vallen in de toekomst. In hun review toonden Zijlstra en collega's (2008) aan dat 2 onderzoeken enig bewijs leveren dat metingen met een protocol met een dubbele taak enige waarde voor het voorspellen van vallen kunnen toevoegen. Zij bevelen toekomstige onderzoeken aan met een grote steekproefgrootte die moeten onderzoeken of een totale prestatiescore die de scores van de cognitieve en balanstaak combineert, gevoeliger is voor het voorspellen van vallen of het opsporen van veranderingen in de balansprestatie dan de score voor individuele balans of cognitieve taak tijdens prestaties met een dubbele taak[16]. In Hoofdstuk 5 wordt een prospectief onderzoek met 270 deelnemers beschreven. Het doel van dit onderzoek was te bepalen of houdingsbalansvariabelen die gemeten werden met een krachtenplatform met of zonder uitdagende voorwaarden, in staat waren om prospectief vallers en niet-vallers te beschrijven bij een zelfstandig wonende oudere populatie gedurende een periode van 12 maanden. De uitdagende omstandigheden die hier gebruikt werden, waren een verminderde visus en/of dubbele cognitieve taken. De bevindingen toonden aan dat de krachtenplatformvariabele RMS-ML (Root-Mean-Square-amplitude, ofwel de amplitude van de wortel uit het gemiddelde kwadraat, in mediaal-laterale richtingen) het valrisico in de toekomst voorspelt bij vrouwen die meerdere valpartijen in de anamnese hebben en die medicatie gebruiken waardoor een risico op vallen ontstaat of die meerdere geneesmiddelen gebruiken. Er werd ook gezien dat meerdere vallers tijdens de balanstesten een smaller steunvlak aannamen.

Het doel in Hoofdstuk 6 was om eerst te bepalen wat de veranderingen in houdingsbalans waren die veroorzaakt werden door niet kunnen zien, verstoorde somatosensorische informatie en een combinatie van niet kunnen zien en verminderde somatosensorische informatie tijdens omstandigheden met een enkele taak en een dubbele taak. Ten tweede was het doel het bepalen van de 'dual task costs' (DTC, ofwel hoe goed iemand twee taken tegelijk kan uitvoeren) en de verandering van DTC die veroorzaakt wordt door de verschillende testomstandigheden. De gecombineerde vermindering van sensorische input (visus en somatosensorische verstoring) resulteerde in een afname van 'dual task costs' voor houding waarbij tegelijkertijd geen verandering optrad in de 'dual task costs' voor cognitie. Dit resultaat weerlegt het vaak gebruikte theoretische raamwerk van brondeling[1] en de theorie van adaptieve brondeling[17]. De bevindingen lijken daarom ondersteuning te bieden voor de theorie van een vergroot verwerkingsgebied[18]. De theorie neemt aan dat de hersengebieden die actief zijn bij omstandigheden met dubbele taak, veel overlap vertonen met gebieden die actief zijn voor elk van de afzonderlijke taken en dat de hersengebieden gewoon groter van omvang worden als er meer verwerkingsbehoeften zijn[18]. De gecombineerde vermindering van sensorische input zou ertoe geleid kunnen hebben dat de participanten een groter verwerkingsgebied inzetten en om die reden meer cognitieve capaciteit ter beschikking kregen.

Deze grotere cognitieve capaciteit zou dus gebruikt kunnen worden ter compensatie van de vermindering van de sensorische input evenals voor de cognitieve taak, wat de verlaging van de 'dual task costs' voor houding en absoluut verschil in slingeren bij omstandigheden met een dubbele of enkele taak, kunnen verklaren.

Samengevat toonde deze scriptie nieuwe aspecten van de krachtenplatform meetmethode voor de houdingsbalans bij oudere vallers en niet-vallers. De krachtenplatform meetmethode kan in toekomstig onderzoek worden gebruikt, om de effectiviteit van interventieprogramma's te bepalen die gericht zijn op valpreventie.

References

1. Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture 2002; Aug;16(1):1-14.

2. Jamet M, Deviterne D, Gauchard GC, Vançon G, Perrin PP. Age-related part taken by attentional cognitive processes in standing postural control in a dual-task context. Gait Posture 2007; Feb;25(2):179-184.

3. Pajala S, Era P, Koskenvuo M, Kaprio J, Tolvanen A, Rantanen T. Genetic and environmental contribution to postural balance of older women in single and dual task situations. Neurobiol Aging 2007: Jun;28(6):947-954.

4. Pellecchia GL. Dual-task training reduces impact of cognitive task on postural sway. J Mot Behav 2005; May;37(3):239-246.

5. Yardley L, Gardner M, Leadbetter A, Lavie N. Effect of articulatory and mental tasks on postural control. Neuroreport 1999; Feb 5;10(2):215-219.

6. Corriveau H, Hebert R, Prince F, Raiche M. Intrasession reliability of the "center of pressure minus center of mass" variable of postural control in the healthy elderly. Arch Phys Med Rehabil. 2000, 81(1):45-8.

7. Geurts AC, Nienhaus B, Mulder TW, Intrasubject variability of selected force-platform parameters in the quantification of postural control. Arch Phys Med Rehabil ,1993, 74:1140–1150.

8. Lafond D, Corriveau H, Hebert R, Prince F. Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. Arch Phys Med Rehabil. 2004, 85(6):896-901.

9. Stelmach GE, Worringham CJ. Sensorimotor deficits related to postural stability. Implications for falling in the elderly. Clin. Geriatr. Med. 1985, 1(3):679-94.

10. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N. Engl. J. Med. 1988, 29(26):1701-7.

11. Hausdorff JM, Edelberg HK, Mitchell SL, Goldberger AL, Wei JY. Increased gait unsteadiness in community-dwelling elderly fallers. Arch. Phys. Med. Rehabil. 1997, 78:278–283.

12. Shumway-Cook A, Baldwin M, Polissar NL, Gruber W. Predicting the probability for falls in community-dwelling older adults. Phys Ther. 1997, 77(8):812-9.

13. Spirduso, W.W. Balance, posture and locomotion: Physical Dimensions of Aging Spirduso WW (Ed.). Illinois: Human Kinetics; 1995:155–183.

14. Palmieri RM, Ingersoll CD, Stone MB, Krause BA. Center-of-pressure parameters used in the assessment of postural control**.** Journal of Sport Rehabilitation. 2002;11:51–66.

15. Piirtola M, Era P. Force platform measurements as predictors of falls among older people—a review. Gerontology. 2006;52:1–16.

16. Zijlstra A, Ufkes T, Skelton DA, Lundin-Olsson L, Zijlstra W. Do dual tasks have an added value over single tasks for balance assessment in fall prevention programs? A mini-review. Gerontology. 2008;54:40–49.

17. Mitra S. Adaptive utilization of optical variables during postural and suprapostural dual-task performance: Comment on Stoffregen, Smart, Bardy, and Pagulayan (1999). J Exp Psychol Hum Percept Perform 2004; 30:28–38.

18. Erickson KI, Colcombe SJ, Wadhwa R, Bherer L, Peterson MS, Scalf PE, Kramer AF. Neural correlates of dual-task performance after minimizing task-preparation. Neuroimage 2005; 28:967–979.

Acknowledgements

It is a pleasure to thank the many people who made this thesis possible.

First and foremost I offer my sincerest gratitude to my promoter, Professor Theo Mulder, who has supported me throughout my thesis with his patience and knowledge whilst allowing me the room to work in my own way. One simply could not wish for a better or friendlier supervisor.

I am especially grateful to my co-promoter Eling D. de Bruin for the dedication he has shown in supervising this work; his ideas have challenged my way of thinking and greatly enhanced the outcome.

I owe my most sincere gratitude to my co-promoter Daniel Uebelhart, who gave me the opportunity to work with him in his research group and who gave me untiring help during this period.

I would also like to thank Professor Beat Michel and Professor Steffen Gay of the Department of Rheumatology and Institute for Physical Medicine of the University Hospital Zurich for their support.

Many thanks go to my fellow doctoral student Ruud Knols for his admirable patience in working side by side with me for so many years. Our discussions have been important and travels together enjoyable. Doing research is a long-lasting search and therefore having such a colleague around is important.

Special thanks to Barbara Gut, who supported me in the final steps of this thesis

My special gratitude goes to my fellow research colleagues Andreas Klipstein, Haiko Sprott, Luca Scascighini, Karin Niedermann, Thomas Gloor, Kathrin Meyer, and Annette Kurre for their empathy and good ideas.

I also like to thank Kathrin Favero, Anna Burini and André Schmidt for their help with all the measurements. You did a great job!! This help was made possible by Prof. Kurt Murer of the ETH. It was a perfect cooperation, thanks very much.

Many thanks go to Leanne Pobjoy for her help in editing. Anna Schlosser, Leokadia Zurek and Harri Joronen helping me with the literature search. I also like to thank Martin Litschi helping me with the orthography and Marguerite Stauffacher being always open for trying out new therapy ideas.

I am much obliged to Pierrette Baschung supporting me all the time and always ready with a helping hand.

Thanks goes to Jaap Fransen who gave me a good start with this thesis.

In my daily clinical work I have been blessed with a friendly and cheerful group of colleagues; Andrea Bärlocher, Corinne Brodbin, Uta Dietz, Sibylle Egli, Nikola Egli-Krause, Dieter Elsener, Sara Fischer, Claudia Gerber, Rahel Gilgen, Carolin Heitz, Sven Hoffmann, Anne Juanós, Ulrike Juelich, Ulla Kellner, Anita Kohli, Ina Koppermann, Cornelia Ott, Elisabeth Penzkofer, Patrizia Räber-Jäggi, Elfriede Raffainer-Steinhuber, Anita Schelbert, Iris Schütz-Bossart, Susanne Spillmann, Stephan Staffelbach, Juliane Stöcker, Uta Stoll, Alex Tobler, Konstanze Wagner, Nicole Wassmer, Karen Welti, Jonathan Widmer, Christian Wild, Rainer Wilhelm, Balz Winteler.

Many thanks goes also to the technical staff, Christiane Nanning-Börtzler, Domingos Carvalho, Manuel Martins Soares and last but not least Irene Macedo, for the support during all these years.

My first steps in the field of research were taken under the guidance of Geert Aufdemkampe. He made an indelible impact on me with his enthusiasm and wisdom. Thanks Geert!

Recruiting so many participants for all these studies was a lot of work. Without the help of Nicole Thomson and Valérie Krafft of the Swiss League against Rheumatism, René Willi of the Zurich League against Rheumatism and Marlies Dorfschmid, this would have been an impossible task. Many thanks for this help.

I wish to thank my friends Thierry Delley, Jürg Wild, Fabrizio Rutishauser, Dimitrios Koutidis Lucas Brekelmans, Sigrid Wild, Carol Delley and Jasper van Groeningen for all the emotional support, camaraderie, entertainment, and caring they provided.

I wish to thank my sister for always cheering me up.

Most; my parents, I thank you dearly for your enduring support and encouragement. Your unwavering faith in my abilities, your enormous capacity to empathise is appreciated more than you can imagine.

Curriculum Vitae

The author was born on February 25th 1969 in Dielsdorf, Switzerland. He finished gymnasium 1990 in Zurich, Switzerland. After fulfilling his military duty, he was working in different jobs.

He graduated 1998 with a Bachelor degree in physiotherapy from the Utrecht University of Applied Sciences, The Netherlands. In the year 1999 he received his Master degree in Physiotherapy at the University of Leuven, Belgium. After returning to Switzerland he worked as Physiotherapist and Research Fellow at the Department of Rheumatology and Institute of Physical Medicine, University Hospital Zurich, Switzerland. This resulted in several research articles in the field of osteoporosis and postural balance, including the articles covered in this thesis.

In 2005 he became a member of the Swiss Human Movement Society. And 2006 he was elected member of the board of the Swiss Human Movement Society. Since 2006 he is a member of the Austrian, German and Swiss Guidelines Commission “Leitlinie Physiotherapie und Bewegungstherapie bei Osteoporose“, organised by the Charité, Berlin, Germany. In the year 2008 he became a member of the Swiss Sport Science Society.

List of Publications

Publications with Review:

Swanenburg J, de Bruin ED, Hegemann S, Uebelhart D, Mulder T. Dual tasking under compromised visual and somatosensory input in the elderly. Conditionally accepted BMC Geriatrics 2009.

Swanenburg J, de Bruin ED, Uebelhart D, Mulder T. Fall Prediction in the Elderly; A 1 year prospective study. Gait and Posture Accepted 2009.

de Bruin ED, Swanenburg J, Betschon E, Murer K. A randomised controlled trial investigating motor skill training as a function of attentional focus in old age BMC Geriatrics 2009, 9:15.

Dietzel R, Begerow B, Bollert G, Kladny B, Kleinöder H, Kwiet A, Pientka L, Preisinger E, Runge M, Swanenburg J, Wieland E, Felsenberg D. Leitlinie Physiotherapie und Bewegungstherapie bei Osteoporose. physioscience 2009; 5:1–11.

Swanenburg J, de Bruin ED, Uebelhart D, Mulder T. Compromising postural balance in the elderly. Gerontology 2009, 55:353-360.

Swanenburg J, de Bruin ED, Favero K, Uebelhart D, Mulder T. The Reliability of Postural Balance Measures in single and dual tasking in Elderly Fallers and Non-Fallers. BMC Musculoskeletal Disorders 2008, 9:62.

Swanenburg J, de Bruin ED, Stauffacher M, Mulder T, Uebelhart D. Effects of exercise and nutrition on postural balance and risk of falling in elderly people with decreased bone mineral density: randomized controlled trial pilot study. Clin Rehabil. 2007 Jun;21(6):523-34.

Swanenburg J, Karel H. Stappaerts, Bart Tirez, Daniel Uebelhart, Geert Aufdemkampe.
Development and reliability of a measurement device for flexion force of the first metatarsophalangeal joint. Journal of Applied Biomechanics 2003, 19(3):271-278.

Swanenburg J, Mulder T, De Bruin ED, Uebelhart D. Physiotherapy interventions in osteoporosis. Z Rheumatol. 2 003 Dec;62(6):522-526.

Other Publications:

Swanenburg J. Physiotherapie bei Osteoporose. Fisio Active 2009, 4:22-27.

Swanenburg J. Muskeltraining. In: Osteoporose, Knochenstark älter werden. Sonderheft Zeitlupe 2007. S32-37

De Bruin ED, Niedermann K, Swanenburg J, Uebelhart D, Jungo DR. Das Forschungsprofil der zukünftigen Fachhochschule Gesundheit. Fisio Active 11:5-10, 2005.

Swanenburg J, Stauffacher M, Knols R, Baschung P, Uebelhart D. Prävention von osteoporotischen Frakturen. Pysiotherapie öPv, 2002, 4: 26-30.